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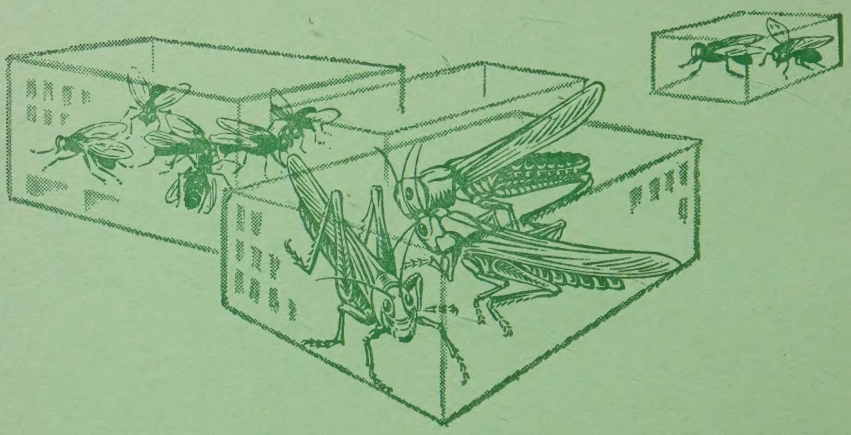

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Experiments on Cocoa Drying in the Cameroons

G. A. R. Wood

Cadbury Brothers Ltd, Bournville, England

An account is given of experiments on cocoa drying carried out at the Cadbury and Fry cocoa plantation at Ikiliwindi in the Southern Cameroons. These experiments were an extension of the work described in an earlier paper (Howat *et al.*, 1957) and were concerned with finding the most economical conditions for operating a platform dryer.

The main purpose of the earlier experiments was to determine the effect of drying cocoa beans artificially at high temperatures, and hence, in a short time, on the subsequent chocolate flavour. Air temperatures up to 80° C were used, and at that temperature the drying time was about 14 hours. The beans were made up into chocolate and after tasting tests, the main conclusion was that ' there was little to choose between sun- and machine-dried beans from a given fermentation '. Beans dried under similar conditions during experiments in Suriname also gave an acceptable chocolate (de Vos, 1956).

The first experiments were not primarily concerned with the economics of drying, and the machine, though suitable for experimental purposes, was of small capacity. Therefore, in order to study the economics of drying and to develop a dryer for use at Ikiliwindi, it was necessary to find a machine with a larger output.

FACTORS INVOLVED IN SELECTING A DRYER

Fuel

The choice is generally limited to wood and oil. It is often assumed that wood is the cheapest fuel, its cost being limited to the labour involved in cutting it up, and the transport to the dryer; furthermore, it is available in seemingly unlimited quantity, new growth providing for its replacement. Some of these advantages are real and, where labour rates are low, the cost of firewood is probably less than that of oil. On the other hand, the amount of labour involved in sawing timber, stacking, transporting and splitting it for firewood is considerable, and where much of the crop has to be dried artificially a gang of men will be needed for the job, which involves their supervision and, in some cases, housing. In addition, the use of firewood requires frequent attention to the fire, and the temperature control depends on the skill and application of the operator.

By comparison, oil does not require a gang of labour, does not require anyone to stoke a fire, and lends itself to accurate control of hot air temperature.

The choice between firewood and oil depends not only on their relative costs but also on the value placed on the advantages of using oil. In the

few countries where oil costs more than firewood, the advantages of low labour requirement, reliability and uniformity of drying conditions may be considered worthy of the difference in cost.

Possibility of taint

If firewood is used, it is clearly essential to prevent any possibility of the products of combustion getting into contact with the beans lest unpleasant taints are imparted to them. Therefore, the air must be heated indirectly.

With oil there is a choice of direct heating, in which the products of combustion are mixed with the hot air blown through the beans, or indirect heating, using a heat exchanger, in which they are kept separate. Both types are used to dry cocoa beans. With the right choice of oil and correct setting of the burner, it is unlikely that the products of combustion will cause a taint with a direct heater, but the use of a direct heater limits the choice of oil to distillate fuels of the lighter fractions. There is also the risk that, by a change in oil supply or some maladjustment of the burner, combustion will not be correct and a taint could result. To eliminate this risk a heat exchanger can be used. This involves some additional capital cost and a higher cost of drying where the same fuel is used, but a heat exchanger does allow cheaper fuels to be used. The same question has arisen with the drying of Arabica coffee and McCloy (1959) has expressed a similar opinion regarding the use of a heat exchanger.

Heat required

There is very little information available about the relationship of heat output and the output of dry beans. Some data have recently been given by Haynes (1958), who conducted some small-scale experiments which showed that it requires 1 300 to 1 500 B.t.u. to evaporate 1 lb of water, the amount rising as the beans dry. This represents the total heat required under certain conditions, including the heat required to raise the temperature of the beans, and heat losses from the apparatus. In practice, the consumption of heat will exceed the above amount because the air will not be saturated when it leaves the dryer. One of the objects of the experiments described in this paper was to get more information on this factor.

APPARATUS

In 1957 the Samoan Cocoa Dryer was developed for use in the Cameroons (Bournville, 1957). This is essentially a cheap, simple dryer for the small farmer and depends on a convection current of hot air which rises from a flue and passes through a layer of beans resting on a drying platform. This dryer can dry beans within two days.

To improve on this dryer for use on estates it seemed best to blow hot air from a fan and heat exchanger unit into the plenum chamber beneath the drying platform. Since the platform could be built largely of materials available locally, the weight and cost of the apparatus which would have to be transported to the tropics and erected there, was reduced and seemed likely to be less than other dryers of comparable output.

An oil-fired fan and heat exchanger with an output that was thought sufficient to produce half a ton of dry beans in 20 to 22 hours was chosen.

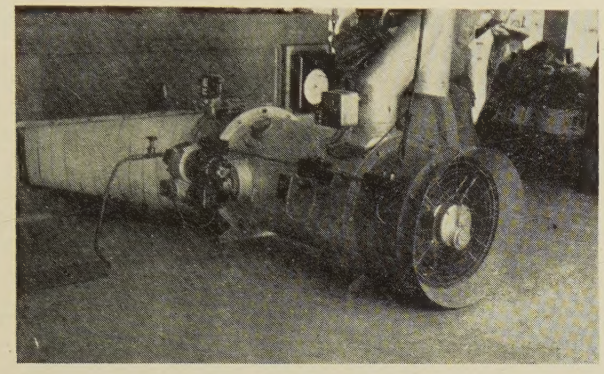

Figure 1. Fan and heat exchanger unit

The unit was manufactured by Woods of Colchester Ltd and was made up of a Woods 24JTD Aerofoil fan, an Airwoods 241 heat exchanger, and a damper to control the airflow. The general arrangement of the unit is shown in *Figure 1*. The heat exchanger was fitted with a Nu-Way XL2 burner which was subject to the following controls:

(*i*) A Danfoss air thermostat (range 25° to 90°C), with its bulb in the hot air duct, controls the temperature of the hot air.

(*ii*) Danfoss control unit CBK–A. This unit starts and stops the burner and depends on a bimetallic coil in the flue. In the case of flame failure, the control unit switches off the burner, attempts to re-start it after a short period of time and, if this attempt fails, the burner is again switched off and a warning light comes on. This light was supplemented by a loud and effective bell.

(*iii*) A Teddington Warmair thermostat with its bimetallic coil in the heat exchanger, acts as a limit switch turning off the burner should the temperature rise above a selected level. This would occur if the fan failed.

The fan and heat exchanger unit is capable of a maximum output of 260 000 B.t.u. per hour, which is equivalent to an airflow of 2 500 ft^3/min with a temperature rise of 50°C above ambient. This output requires a consumption of 2·0 Imperial gallons per hour (gal/h). To deal with smaller outputs, either through lower rates of airflow, or smaller temperature rises, a set of five jets was supplied for the oil burner ranging from 0·8 to 2·0 gal/h. The jets can be changed in about two minutes.

Electric power for the fan, burner and controls was supplied by a 7 kW Lister generator driven by an SL2 diesel engine. Both burner and generator used diesel fuel.

This unit was coupled by a short duct to a plenum chamber with internal dimensions 20 ft × 9 ft, the walls of the platform, which were 3 ft high, being built of concrete blocks (*Figure 2*). The platform itself consisted of wire-mesh trays resting on an angle iron frame. Each tray was 9 ft × 2 ft and was made of four-mesh-to-the-inch mild steel, the whole of the tray

being tinned. The platform was surrounded by planks enabling a layer of beans 6 in. deep to be held on it. Wet beans equivalent to half a ton of dry cocoa formed a layer 3 in. deep over the whole platform. Towards the end of the series of experiments, the platform was lengthened to 26 ft to accommodate wet beans equivalent to one ton of dry cocoa.

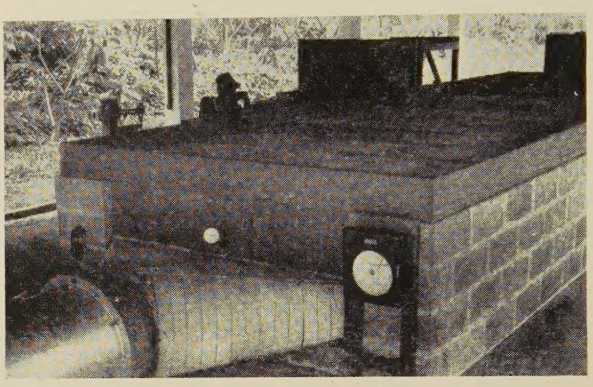

Figure 2. Drying platform

Insulation in the form of hardboard was fixed to the inside of the walls of the drying platform, and a partition of hardboard on a wooden frame was made to fit across the plenum chamber so that the effective length of the platform could be altered.

Preliminary trials showed that the distribution of air was not uniform. To overcome this a piece of hessian was fixed over the end of the duct and this was effective in making the distribution uniform. During the experiments the length of the drying platform was varied between 14 ft and 26 ft but the airflow, as judged by the rate at which the beans dried, was evenly distributed in all cases.

METHODS

(a) *Supply of wet beans*

Beans were supplied from the Tombel estate of the Cameroons Development Corporation for seventeen experiments and from a large native farm near Kumba for four experiments. The beans from Tombel estate were harvested, opened and transported to Ikiliwindi on the same day, while those from Kumba were harvested over several days, then opened and delivered the same day.

(b) *Fermentation*

In all but three experiments the beans were fermented in boxes 4 ft 4 in. square and 2 ft 6 in. deep. A box held about 2 800 lb wet beans, equivalent to half a ton of dry beans. The beans were fermented for six days, being turned from one box to another after two days and four days.

For the remaining three experiments the tray method of fermentation was used (Allison and Rohan, 1958).

(c) *Drying*

After fermentation the beans were transferred to the drying platform, where they were dried under various conditions of temperature and airflow. During the course of drying the beans were raked at intervals, frequently when the outside of the beans was wet in order to prevent them sticking together, and at longer intervals during the later stages when the object of raking was to ensure uniformity.

MEASUREMENTS

(a) *Temperature*

The temperature of the hot air was measured by a dial thermometer whose bulb was placed at the mid-point of the duct. A recording thermometer was also fitted with its bulb in the duct. Temperatures in the layer of beans were taken during some tests to measure variation over the drying platform.

(b) *Rate of airflow*

Before the apparatus was sent to the Cameroons it was erected with a drying platform at Bournville to gain experience in its operation. While at Bournville, measurements were taken under conditions similar to those during drying as further measurements could not be taken in the Cameroons.

(c) *Moisture loss*

The weight of water evaporated was determined by weighing the beans before and after drying. A drying curve was obtained by taking samples at intervals and weighing three lots of 100 beans. By plotting the average weight of beans a drying curve was obtained.

(d) *Oil consumption*

A record of oil consumption for the engine and the burner was kept.

EXPERIMENTAL WORK

Four factors were varied: bean depth, hot air temperature, rate of airflow and batch size. The results of the experiments are given in *Table 1*.

(a) *Bean depth*

The depth of the layer of beans was varied between 3 in. and 5 in. as measured when wet. (During the course of drying the layer shrinks.) Experiments 3 and 6, using a 3 in. layer, had drying times of 29 and 27·5 h and a fuel consumption of 39 and 35 gal respectively, while in experiments 11 and 15 using a 4·5 in. layer the corresponding data were 26·5 and 25 h and 27 and 25 gal. Thin layers are, therefore, not as economical as thick layers.

The major saving is presumably due to the hot air being more nearly saturated when it has passed through a thick layer, but some saving will also result from a reduction in heat losses from the smaller plenum chamber required for a thick layer.

It is essential to mix the layer of beans to prevent their sticking together and to achieve uniformity of drying. Therefore, the depth of the beans

Table 1

1	2	3	4	5	6	7	8	9	10	11	12	13
Test No.	*Dry wt ton*	*Depth in.*	*Airflow ft³/min. per sq. ft*	*Temp. °C*	*Drying time h*	*Final moisture %*	*Consumption, gal*			*Burner cons. gal per ton dry beans*	*Spec. evapn lb water evaporated per gal*	*Remarks*
							Burner	*Per hour*	*Total*			
1	0·5	3	14	70	30	6·0	34·5	1·27	40	69	29·2	
2	0·5	3	14	80	24	6·2	36	1·5	40·75	72	30·0	
3	0·5	3	8	80	29	5·7	39	1·3	45	78	29·5	
4	0·5	4·5	20	80	28	5·4	37·5	1·3	43·25	75	30·7	
5	0·5	4·5	11	80	25	5·7	31	1·25	36·75	62	39·7	
6	0·5	3	8	80	27·5	6·0	35	1·2	40·5	70	33·8	
7	0·5	4·5	20?	70	30	5·0	29·5	1·0	35·25	59	38·2	*Airflow reduced by dirt on hessian*
8	0·75	4·5	14–8	80	24	5·6	32	1·3	36	43	49·6	*Airflow reduced after 9·5 h*
9	0·5	4·5	11	80	20	5·2	26	1·3	30	52	44·2	*Beans from local farm*
10	0·5	4·5	11	80	23·25	5·9	30·5	1·3	35·25	61	36·5	
11	0·5	4·5	9	80	26·5	6·0	27	1·0	32	54	42·5	
12	0·75	4·5	8–6	70–80	28	6·3	32	1·1	38	43	51·5	*Airflow reduced and temperature raised after 6·5 h*
13	0·5	4·5	11–9	80	25·5	5·2	29	1·1	34·25	58	38·3	*Airflow reduced after 6 h*
14	0·5	4·5	11	70	28	6·0	31·5	1·1	37·25	63	35·4	
15	0·5	4·5	9	80	25	6·5	25	1·0	30	50	47·0	*Beans from local farm*
16	0·5	4·5	11	80	22	5·9	28	1·3	32·25	56	35·0	*Tray fermentation*
17	1·0	5	11–6	70–80	32	6·8	41	1·3	47·5	41	54·0	*Airflow reduced and temperature raised after 16·5 h*
18	0·75	4·5	14–8	80	23	6·2	29	1·3	33·75	39	55·5	*Beans from local farm. Airflow reduced after 8 h*
19	0·5	4·5	11	70	27	6·0	31	1·15	36·5	62	32·0	*Tray fermentation*
20	1·0	5	11–6	80	34	—	41	1·2	48	41	—	*Airflow reduced after 8 h*
21	0·5	4·5	11	80–90	20	—	25	1·25	29	50	38·6	*Tray fermentation. Beans from local farm. Airflow reduced and temperature raised after 6·5 h*

is limited to the greatest depth that can be mixed effectively. Mixing was done by hand and it was impractical to mix a layer deeper than 5 in. Mechanical stirring is a possibility which might allow a deeper layer, but it seems doubtful whether it would be economical.

(b) *Temperature*

Two hot air temperatures were used, 70°C and 80°C, and four pairs of tests compared their effects. The average drying time at 70°C was $29 \pm 1{\cdot}25$ h and at 80°C, $24 \pm 1{\cdot}75$ h, and the average fuel consumption (burner only) was $31{\cdot}5 \pm 1{\cdot}4$ gal at 70°C and $33 \pm 3{\cdot}75$ gal at 80°C. Looking more closely at the results for oil consumption, it was shown, on the basis of two results in each case, that at a high rate of airflow, consumption is higher at 80°C (36·75 gal against 32 gal average), while at a low rate of airflow the position is reversed (29·25 gal against 31·25 gal average). *Figure 3* indicates the difference in rate of drying at 70°C and 80°C in tests 16 and 19, the other conditions being the same in the two tests.

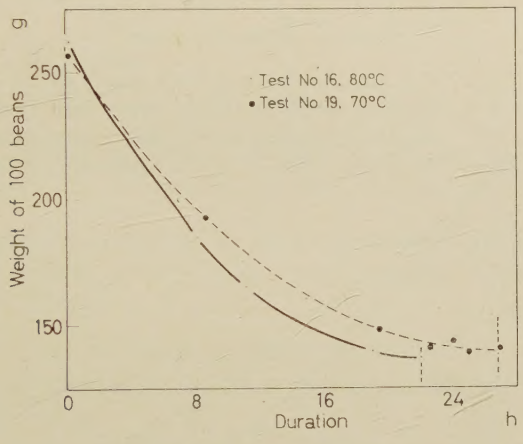

Figure 3. Drying curves

(c) *Rate of airflow*

In most of the tests, the airflow was varied between 8 and 14 ft/min per square foot of drying platform. The average drying time for four tests at a rate of 11 to 14 ft/min was $23 \pm 1{\cdot}5$ h, whereas the average of four tests at 8 to 9 ft/min was $27 \pm 1{\cdot}25$ h. The average fuel consumption was the same, 31 gal, in both cases, but in some of these tests a 3 in. layer was used. If only the tests using a $4\frac{1}{2}$ in. layer are compared, then the fuel consumption at 8 to 9 ft/min was 26 ± 1 gal, and at 11 to 14 ft/min, 29 ± 2 gal. Therefore, a high rate of airflow will dry the beans more quickly but will lead to increased fuel consumption.

During the first eight hours of drying when the skin of the bean is moist, the rate of drying might be expected to depend on the rate of airflow. When the skin is dry, the rate of drying will be less influenced by the rate of airflow, which, for economy, should be just sufficient to maintain the

temperature of the beans. *Figures 4* and *5* compare the rate of drying at different airflows.

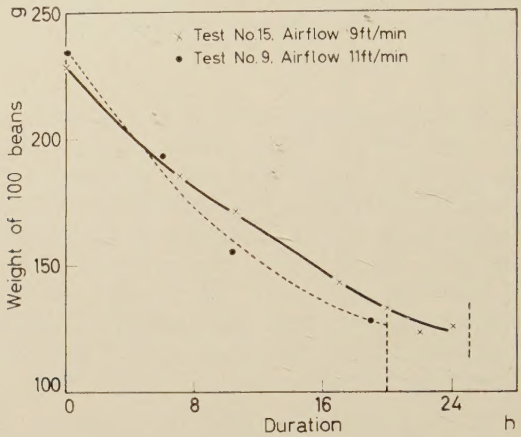

Figure 4. Further drying curves

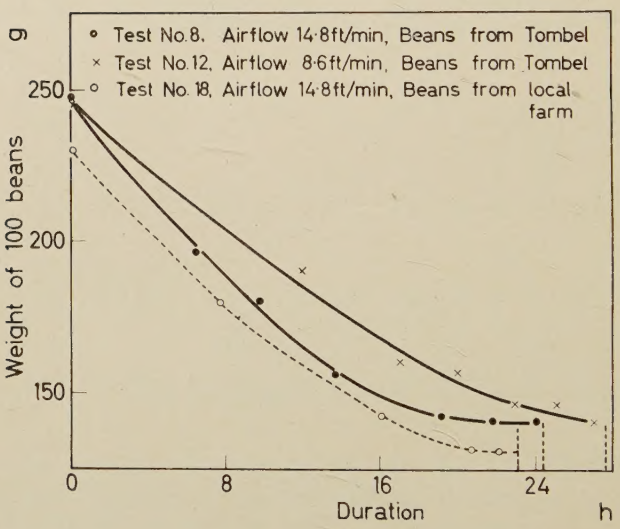

Figure 5. Further drying curves

(d) *Batch size*

Initially, it was hoped that the dryer would have an output of half a ton of dry beans in 20 to 22 h, a drying time which would fit conveniently into estate routine allowing enough time to unload and reload the dryer within 24 h. It soon became apparent that drying could not be completed within 24 h. Therefore, larger batches were dried, three experiments having an output of three quarters of a ton and two experiments with an output of one ton. The drying time for the former averaged 25 ± 2 h and for the latter 33 ± 1 h.

In all these experiments the airflow was reduced when the outside of the bean was dry, so that during the last stages of drying a low rate of airflow of 6 to 8 ft/min was used. As a result, all these experiments showed a considerable saving in fuel consumption over any of the other experiments. Column 11 *Table 1* shows this. Therefore, lower rates of airflow than were used in drying half a ton would lead to greater economy.

(e) *Other factors*

As the beans from Tombel were appreciably larger than the average for West Africa and the Cameroons, it was thought that bean size might have some bearing on drying time. To test this, some batches of beans were collected from a local farm and in three pairs of tests they were compared with beans from Tombel estate, the drying conditions being the same in each pair. Determinations of bean weight and shell percentage were made. The results are given in *Table 2*.

Table 2

Results	*Tombel*	*Local farm*
Drying times:		
Test Nos. 9, 10	23·25 h	20 h
11, 15	26·5 h	25 h
8, 18	24 h	23 h
Weight of 100 beans	139·0 g	128·1 g
Shell percentage	13·9	11·9

The data suggest that the smaller beans dried more quickly. However, this cannot be proved without more determinations of moisture content before and after drying.

MOST ECONOMICAL OPERATING CONDITIONS

On the basis of these tests, the most economical conditions of operating a platform dryer are:

Air temperature	80°C
Rate of airflow	8 to 9 ft/min
Depth of beans	5 in.

EFFICIENCY OF THE DRYER

The performance of a dryer can be expressed as ' specific evaporation ', i.e. the weight of water evaporated per unit of fuel. This quantity is given in column 12 of *Table 1*. The highest rate was 55·5 lb/gal.

Alternatively, the factor ' specific consumption ', i.e. fuel required to evaporate a unit of water, usually expressed as B.t.u./lb, can be used. The above rate is equivalent to 2 360 B.t.u./lb based on ' useful ' heat, i.e. the heat content of the air blown through the beans. This is calculated on the assumption that the calorific value of the fuel is 164 000 B.t.u./gal and that the heat exchanger has an efficiency of 80 per cent.

On the basis of total energy (total fuel burnt in engine and burner), the ' specific consumption ' is 3 280 B.t.u./lb in the most economical test. The only comparable rate available is 3 413 B.t.u./lb. This is given by

HAYNES (1958), in whose trials the air was heated electrically, so that there was no need for a heat exchanger with its consequent loss of heat. The airflow used was 35 ft^3/min per square foot and the drying time 14 h. These data confirm that it is more economical to use a low rate of airflow although the drying time will be increased.

From data concerning experiments conducted in Suriname (DE VOS, 1956), a rate of 2 340 B.t.u./lb, based on ' useful ' heat, can be calculated. In this case, the beans were washed before drying, the air was heated directly and was re-circulated. All these factors would tend to lower the value for ' specific consumption '.

Although the dryer compares favourably with the few results available for cocoa, the best results for ' specific consumption ' are considerably higher than the data quoted earlier from HAYNES (1958) and are also higher than the rate of 1 920 B.t.u./lb obtained by MCCLOY and WOODFORDE (1955) in a groundnut-drying trial and the range of 1 640 to 1 796 B.t.u./lb for grass-drying given by SAMBROOK (1948). It would be unwise to draw firm conclusions from these data owing to the widely different nature of the crops, but the results suggest that some improvement in efficiency is possible.

COST OF DRYING

Fuel

In the more efficient tests with outputs of 0·75 and 1 ton of dry beans, the consumption of oil per ton of dry beans varied between 39 and 43 gallons for the burner alone. In addition, the generator used 1 gallon for every 5 hours running.

Labour

The dryer required one man in constant attendance to rake the beans. If the dryer is attended by three men in 8 h shifts, then attention will require 4 man-days per ton. In addition, loading and unloading will require three men for 3 h each or approximately one extra man-day.

Depreciation

Assuming an output of 3 tons per week, a use of 20 weeks per annum and a life of 10 years, then depreciation will be approximately £2 per ton.

Total cost per ton

	£	*s*	*d*
Fuel (46 gal at 2*s* 6*d*)	5	15	0
Labour		15	0
Depreciation	2	0	0
	£8	10	0

These data would apply in the Cameroons where the price of oil is high. In most other countries the price will be considerably lower, and although labour may be more expensive, the total cost will probably be lower.

The capital cost of this dryer will vary from country to country, but would compare favourably with other cocoa dryers of similar output.

CONCLUSIONS

(*1*) An oil-fired fan and heat exchanger unit coupled to a simple drying platform was used and proved effective in producing a half to one ton of dry cocoa beans in 20 to 34 hours.

(*2*) The depth of beans on a drying platform should be as thick as can be effectively mixed.

(*3*) The most economical drying conditions occurred with high temperature and a low rate of airflow.

(*4*) There is some indication that the drying time is influenced by bean size and shell percentage.

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In Ghana, which is the world's largest producer of cocoa, the average yield of the crop is low and is estimated at 200 lb of dry cocoa per acre. Pests and diseases have for many years been recognized as factors limiting production. However, in recent years there have been indications that the use of heavy shade may also be responsible for low yields. At the West African Cocoa Research Institute (WACRI), where soils are fertile and rainfall is well distributed, Cunningham and Lamb (1958, 1959) have shown that, with control of major pests and diseases, large increases in yield can be obtained by the removal of shade from established cocoa. If this practice of cultivating cocoa without shade is eventually adopted, two methods of establishment are possible.

In the first case, cocoa may be established in the partly cleared forest by farmers' methods. After the formation of a complete cocoa canopy, the overhead forest shade is then removed by tree felling or poisoning. This method is not satisfactory because large falling trees cause considerable damage to the cocoa at a time when the preservation of a complete canopy is essential. An alternative method is the felling and clearing of the forest prior to the establishment of cocoa. Allison and Cunningham (1959) have described the lastest techniques used at WACRI to provide large areas of experimental cocoa on clear-felled land.

Ghana forest soils are subject to fairly rapid deterioration and erosion when they are exposed. Consequently, in the clear-felling method of establishment, there is an extremely critical period during which planted shade replaces natural forest. If a large area is being cleared the soil cover provided by trees may be absent for a year. During this period it may be possible to protect the soil by using selected cover crops or mulches.

Few investigations concerning the use of cover crops in cocoa cultivation have been published although van Hall (1932) has reported various techniques which are used in Indonesia. He compares the use of creeping and shrubby legumes and suggests that the latter, as well as protecting the soil, may be employed as preliminary shade. Ground covers have been used more extensively with other tropical crops. In Malayan rubber plantations Watson (1957) and Guha and Watson (1958) have measured the effects of leguminous cover plants on soil moisture and nutrients. Long-term experiments have been carried out in Nigeria to select covers which will maintain the fertility of soil in oil palm plantations and Nye and Hutton (1957) have reported on the preliminary results. Nye (1958) has discussed in detail the restorative and nutrient storage effects of bush and

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planted fallows on exhausted land in Ghana. Also in Ghana, Wilson and Lansbury (1958) have recently investigated the protection of soil in cleared rain forest by the use of a forage crop for sheep.

Mulching of cocoa soils has been studied in Trinidad for the past 25 years. Wasowicz and Havord (1945–51) concluded that over a period of 10 years a grass mulch improved both the nutrient status of the soil and the cocoa yields. However, in later experiments with bagasse mulch, bush mulch and trenched mulch Havord *et al.* (1954) obtained no beneficial responses. Wasowicz (1952) investigated the effects of various mulches on the major nutrients of the soil in a pot experiment with cocoa seedlings. He reported the suppression of nitrogen availability and the increase of available phosphorus and potassium.

As a result of this limited information, an experiment was started at WACRI to investigate the value of various cover crops and a mulch in cocoa establishment.

MATERIALS AND METHODS

Layout

In April 1958 one acre of old secondary forest was clear-felled. The soil of this area is a sandy loam of the WACRI series which has been described by Brammer (1958) as one of the best cocoa soils in Ghana. This site was carefully cleared with minimum soil disturbance and then 56 plots, each 36 square yards in area, were marked out with a two-foot guard strip between them. In the following month seven treatments, replicated eight times, were applied in a randomized block design.

Treatments

The following treatments were applied.

(a) Bare soil. The plots were kept bare by hand weeding
(b) *Tripsacum laxum* (Guatemala grass) mulch. In the first year two applications of mulch were made and 15 tons of dry matter per acre was applied. This amount was halved in the second year when only one application was made
(c) *Tripsacum laxum* (Guatemala grass) cover. This cover was established by planting tillers one foot apart
(d) *Zebrina pendula.* Shoots were planted at random over the entire plot
(e) *Crotalaria striata.* This cover was sown by broadcasting seed. The density of sowing was low because of the limited supply of seed
(f) *Stylosanthes gracilis.* Cuttings were planted at random
(g) Natural regeneration. After initial clearing, natural regeneration of indigenous species was allowed.

Twice in the first year the *Crotalaria*, Guatemala grass and natural regeneration plots were cut on to the plots which were then allowed to regenerate. This was repeated four times in the following year for the Guatemala grass and natural regeneration plots.

Planting of shade and cocoa

In April 1959, about a year after the planting of the covers and application of the mulch, tree cassava (*Manihot* sp.) was planted as cuttings at 8 ft × 8 ft over the entire area. This plant is very quick growing and in a

few weeks was providing a satisfactory dappled shade. Under this shade, at the end of May eight Amazon varieties of cocoa were planted at 4 ft × 4 ft so that each plot contained 25 seedlings of one variety. Each variety was represented once in each of the cover treatments. The outside plants of all plots formed guard rows thus leaving nine experimental trees per plot. In November 1959 at the end of the rains, heights, stem diameters and leaf area measurements of all experimental seedlings were measured. At the end of the dry season in March 1960, when the most critical period for establishment of young cocoa can be assumed to be over, further stem diameters were taken.

Methods of assessing treatment effects

In this experiment the assessment of the efficiency of a cover crop has been based on the performance of the cocoa with the following additional criteria. A cover must establish easily, rapidly form a complete cover for maximum protection of the soil surface and effectively eliminate all weeds. After establishment, maintenance should be simple and the cover should only persist until the formation of complete overhead shade. It must not compete too severely with young cocoa for soil moisture and nutrients and must prevent high temperatures developing in the surface horizon of the soil. By immobilizing some soil nutrients, the cover must be capable of reducing losses by leaching to a reasonable level.

A visual assessment of establishment of the five cover crops was made weekly.

The bulk of the soil nutrients is usually located in the top six inches of Ghanaian forest soils (CHARTER, 1955). This has a marked effect on the rooting habits of both cocoa and forest trees. Approximately 85 per cent (by weight) of the root system of cocoa is confined to the top six inches of soil while the roots of even the largest forest trees very rarely penetrate to a depth greater than three feet. Previous, unpublished work with the soil used in this experiment indicated that, when exposed, the levels of organic matter and total nitrogen in the top two inches decreased considerably in the first year; below this level very little change took place. It was decided therefore to assess deterioration of the soil by measuring the decrease of organic matter and total nitrogen in the 0 to 2 in. horizon of the soil. In May 1958 and almost two years later in March 1960 soil samples were taken from all plots and were analysed for organic carbon and total nitrogen.

Moisture in the top six inches of the soil under the various treatments was measured from November 1958 till March 1960. The method used was the simple but lengthy procedure of obtaining a composite soil sample from each treatment twice weekly and estimating the moisture gravimetrically. Only three soil thermometers were available and soil temperatures were recorded at a three inch depth in bare soil, Guatemala grass mulch and *Zebrina pendula*.

Nitrogen was chosen as a convenient indicator of the competition for and immobilization of nutrients. The following method was used to determine the total nitrogen stored in each cover crop. The aerial parts of the covers from a quarter of each plot were harvested in May 1959,

Table 1. Soil data. Total organic matter and nitrogen in 0 to 2 in. horizon of soil in May 1958 and March 1960. Mean soil moistures (0 to 6 in.) and temperatures (at 3 in. depth) from November 1958 till March 1960. All values are means of 8 replicates

Treatments	% Carbon May 1958	Organic matter* May 1958 lb/acre	% Carbon March 1960	Organic matter* March 1960 lb/acre	% Total nitrogen May 1958	Total nitrogen May 1958 lb/acre	% Total nitrogen March 1960	Total nitrogen* March 1960 lb/acre	C/N ratio May 1958	C/N ratio March 1960	% Mean moisture content (on oven-dry weight basis)	Mean maximum daily temperature °F
	1	2	3	4	5	6	7	8	9	10	11	12
(a) *Bare soil*	4·04	45 200	2·58	28 800	0·323	2 100	0·227	1 470	12·51	11·36	16·6	89
(b) Tripsacum laxum *mulch*	4·24	47 400	4·06	45 400	0·368	2 390	0·336	2 180	11·52	12·08	24·4	83
(c) Tripsacum laxum *cover*	3·90	43 600	3·57	39 900	0·352	2 290	0·331	2 150	11·08	10·78	16·6	*ND*
(d) Zebrina pendula	4·29	48 000	3·81	42 600	0·358	2 330	0·328	2 130	11·98	11·61	19·8	83
(e) Crotalaria striata	4·32	48 300	3·21	35 900	0·358	2 330	0·282	1 830	12·07	11·38	18·5	*ND*
(f) Stylosanthes gracilis	4·48	50 100	3·52	39 400	0·382	2 480	0·373	2 420	11·73	9·44	18·8	*ND*
(g) *Natural regeneration*	4·68	52 300	3·59	40 100	0·398	2 590	0·325	2 110	11·76	11·05	17·5	*ND*

ND– Not determined.
*—It is assumed that the 0 to 2 in. layer of soil weighs 650 000 lb per acre. The factor 1·72 is used to convert organic carbon to organic matter.

weighed and returned to the plot which was allowed to regenerate. Samples were oven dried at 85°C and their total nitrogen was estimated. The roots in one square yard of each plot were dug up and their weight and nitrogen estimated.

RESULTS

Establishment of covers

Zebrina pendula established readily and within two months had formed a complete soil cover which was still extremely satisfactory almost two years later. *Crotalaria striata*, Guatemala grass and natural regeneration also established easily but complete cover was not formed until three months after planting. Natural regeneration initially consisted of sixteen species of trees, nine of shrubs and seven of herbs. The dominant species was *Solanum verbascifolium* (L). *Crotalaria* died out as soon as the tree cassava provided shade. The Guatemala grass and natural regeneration still persisted in 1960 but fifteen months after the beginning of the experiment, grasses were becoming dominant in the natural regeneration plots. A high proportion of the original *Stylosanthes* cuttings failed to root satisfactorily and were replaced. Six months elapsed before the formation of a good cover and after almost two years there were indications that, where the shade was heavy, the *Stylosanthes* had begun to die.

Depletion of soil organic matter

The calculated quantities of organic matter and total nitrogen in the 0 to 2 in. layer of soil under all the treatments in May 1958 and March 1960 are presented in *Table 1* (columns 1 to 8). From these data the weight of organic matter and total nitrogen lost in 22 months and the percentage decreases have been calculated and are given in *Table 3* (columns 1 to 4). Treatment effects fall into two distinct groups with a significant difference ($P=0{\cdot}05$) between groups but not within groups. The losses of soil organic matter under the *Zebrina pendula* and *Tripsacum laxum* cover and mulch are less than under the other treatments. A similar pattern holds for the depletion of total soil nitrogen except that *Stylosanthes gracilis* also reduces nitrogen loss. The C/N ratio of the soil (*Table 1* columns 9 and 10) has decreased in all treatments except under the mulch where it has increased.

Nutrient balance

The oven dry weight, the percentage and total content of nitrogen of the aerial parts and roots of each cover crop are shown in *Table 2*. The total nitrogen stored in a plant is regarded as a measure of the cover's ability to immobilize that element. However, it can also be used to indicate the degree of competition for nitrogen between the cover crop and young cocoa. The overall gains and losses of nitrogen in the various treatments in twenty-two months are shown in *Table 3* (column 6). *Tripsacum laxum* cover and *Stylosanthes gracilis* appear to be the most efficient.

Soil water and temperature

The mean soil moistures (0 to 6 in.) covering the period November 1958 till March 1960 are given in *Table 1* (column 11). They are expressed

as a percentage on an oven dry basis. The soil moisture content under the mulch was always significantly higher than those under the remaining six treatments ($P=0{\cdot}001$). Three of these treatments—*Zebrina pendula*, *Crotalaria striata* and *Stylosanthes gracilis*—maintained a significantly higher soil moisture than did the remaining treatments ($P=0{\cdot}05$). Since it is

Table 2. Cover crop data. Oven dry weights, % nitrogen and total nitrogen contained in plant material in May 1959. All values are means of 8 replicates

Treatments	Aerial parts		Roots		Total nitrogen immobilized by each cover lb/acre
	Oven-dry weights lb/acre	% Nitrogen	Oven-dry weights lb/acre	% Nitrogen	
	1	2	3	4	5
(c) Tripsacum laxum *cover*	8 844	1·90	815	0·82	175
(d) Zebrina pendula	1 474	1·20	258	1·56	22
(e) Crotalaria striata	3 752	2·77	408	0·68	107
(f) Stylosanthes gracilis	2 814	2·51	247	1·15	74
(g) *Natural regeneration*	3 350	4·22	1 559	1·42	163

Table 3. Changes in soil organic matter and total nitrogen (0 to 2 in.) from May 1958 till March 1960 and nitrogen balance for that period (calculated from data presented in Tables 1 and 2)

Treatments	Weight of organic matter lost lb/acre	% Loss of organic matter	Weight of nitrogen lost lb/acre	% Loss of nitrogen	Weight of nitrogen stored in cover lb/acre (see Table 2 col. 5)	Overall gain or loss of nitrogen lb/acre (Col. 5–Col. 3)
	1	2	3	4	5	6
(a) *Bare soil*	16 400	36	630	30	—	−630
(b) Tripsacum laxum *mulch*	2 000	4	210	9	—	−210
(c) Tripsacum laxum *cover*	3 700	8	140	6	175	+ 35
(d) Zebrina pendula	5 400	11	200	8	22	−178
(e) Crotalaria striata	12 400	26	500	21	107	−393
(f) Stylosanthes gracilis	10 700	21	60	2	74	+ 14
(g) *Natural regeneration*	12 200	23	480	18	163	−317

most important that satisfactory available water levels should be maintained in the soil during the dry season, the fluctuations of the soil moisture and the rainfall data from November 1958 till March 1959 are illustrated in *Figure 1*. These curves show the soil moisture variations of the mulch, bare soil, the mean of three growing covers (*Zebrina pendula*, *Crotalaria*

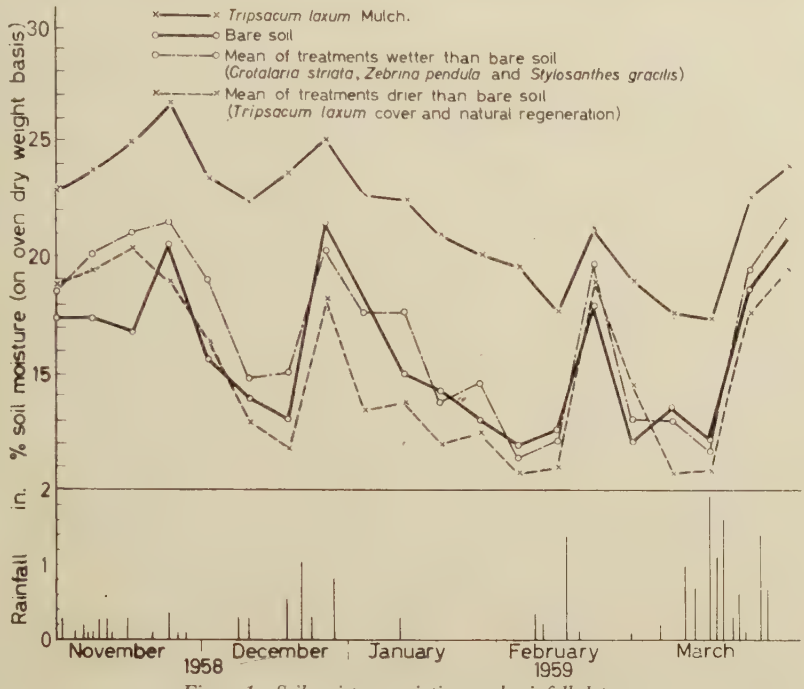

Figure 1. Soil moisture variations and rainfall data

Table 4. Cocoa seedling growth data

Treatments	*Mean height Nov. 1959 cm*	*Mean total leaf area per tree Nov. 1959 dm²*	*Mean stem diameter 6 in. above ground Nov. 1959 cm*	*Mean stem diameter 6 in. above ground Mar. 1960*	*Stem diameter increase during 1959–60 dry season cm*
	1	2	3	4	5
(a) *Bare soil*	58·8	37·2	1·10	1·77	0·68
(b) Tripsacum laxum *mulch*	59·8	48·9	1·19	1·98	0·78
(c) Tripsacum laxum *cover*	75·8	48·8	1·13	1·72	0·59
(d) Zebrina pendula	57·2	40·9	1·08	1·80	0·72
(e) Crotalaria striata	69·6	57·4	1·23	2·07	0·84
(f) Stylosanthes gracilis	61·2	39·3	1·17	1·85	0·72
(g) *Natural regeneration*	62·4	29·5	0·89	1·40	0·51
Sig. diff. between means at P=0·05	8·7	13·0	0·10	0·21	—
Sig. diff. between means at P=0·01	11·7	17·4	0·14	0·28	—

striata, *Stylosanthes gracilis*) which are wetter than bare soil and the mean of two (*Tripsacum laxum* cover and natural regeneration) which are drier.

The mean daily maximum soil temperatures at a 3 in. depth under three treatments are given in *Table 1* (column 12) and indicate that high soil temperatures result when a cover is absent.

Establishment of cocoa

The growth of the cocoa in the various treatments as assessed by height, leaf area and stem diameter measurements is presented in *Table 4* (columns 1 to 4). Six months after planting at the beginning of the dry season, the cocoa plants in the plots with *Tripsacum laxum* cover were significantly taller ($P=0{\cdot}01$) than those in all the other treatments except *Crotalaria striata*. Leaf area measurements indicated that by far the poorest growth took place in the natural regeneration plots and that growth in the *Crotalaria* plots was significantly better ($P=0{\cdot}05$) than that in all the other plots except those with Guatemala grass cover and mulch. Significantly greater ($P=0{\cdot}01$) stem diameters were obtained in all treatments compared with natural regeneration. Later in March 1960, stem diameters showed the same pattern except that under *Tripsacum laxum* cover the growth rate of the cocoa had appreciably decreased during the dry season.

DISCUSSION

This investigation has confirmed that rapid depletion of the organic matter in the surface soil (0 to 2 in.) follows forest removal if no precautions are taken. In the extreme case where the soil is kept bare, approximately one third can be lost in just under two years. This loss is extremely serious in Ghana where forest soils are largely dependent on a high organic matter level to maintain a good structure and a satisfactory moisture holding capacity. The organic matter also forms a valuable reservoir of nutrients and contributes largely to the base exchange capacity of the soil which has mainly kaolin as its clay. Although detailed study has not been carried out, there are indications that higher temperatures disturb the balance of the micro-flora and fauna in these forest soils. The mean maximum daily soil temperature at a 3 in. depth is 81°F under the nearby forest. It would seem that the temperature (83°F) under the mulch and growing covers in this experiment are reasonable, but that (89°F) under bare soil may be too high. The need for a suitable cover crop after clearing is also demonstrated by the satisfactory water relationship which exists under certain treatments. These covers not only preserve a higher level of available water in the soil but also prevent frequent and pronounced wetting and drying cycles taking place. According to Birch (1960) this latter point would in itself reduce loss of organic matter.

Having demonstrated the need for protective cover crops, it is necessary to establish which types are most satisfactory. In the past in Ghana, natural regeneration has been used to protect exposed soil and is the obvious choice if it is shown to be suitable. However, it did not protect the soil efficiently, it competed appreciably for water and nitrogen and the data given in *Table 4* show that the growth of cocoa was least satisfactory in the natural regeneration plots. These observations indicate that all the selected covers are superior to natural regeneration.

Keeping the soil bare on a large scale is very expensive and although competition is eliminated and cocoa establishment was fair, the lack of protection caused rapid and serious loss of organic matter from the soil. For these reasons this practice cannot be recommended. Mulching was efficient both in protection and establishment but is also very costly and it is doubtful if its use would be economic.

The remaining four covers had their advantages and disadvantages. *Tripsacum laxum* cover was a good soil protector but competed heavily with cocoa particularly for water. This latter point is shown clearly by the growth measurements during the dry season (*Table 4*, column 5). *Zebrina pendula* established most easily of all the covers, and provided an effective protection of the soil but the cocoa did not grow too well in these plots. *Crotalaria striata* established well but did not form nodules and died out too quickly as soon as the tree cassava provided a little shade. Consequently for about a year these plots were bare and the loss of organic matter from the soil was quite high. The best growth of cocoa was in this treatment. *Stylosanthes gracilis* was extremely difficult to establish and before it formed a complete cover, an appreciable amount of organic matter had been lost. However, it is interesting to note that after establishment although this legume did maintain a very satisfactory nitrogen balance, there was no evidence of nodulation. The cocoa grew quite well in these plots.

These results confirm that cover crops are essential for soil protection when land is clear-felled prior to the planting of cocoa. They also indicate that special selected covers are superior to natural regeneration. However, it has been shown that all covers tested have some disadvantage. Since only a very limited number were used, a final choice cannot yet be made but the results of this work should form a useful starting point for future experiments designed to test a much wider selection of cover plants.

SUMMARY

The use of covers for soil protection during the establishment of cocoa on clear-felled land has been studied. Five cover crops and one mulch have been tested. The ability of these covers to protect the soil, maintain a good water relationship, prevent high soil temperatures and establish a good nutrient balance has been investigated. Cocoa has been planted and its growth in the various treatments has been assessed. It has been shown that a protective cover is essential for exposed forest soil and that selected covers are better than natural regeneration. However, all those used in this work had some disadvantage and a wider selection of plants must be tested before a final choice is made.

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Influence of Petroleum Oil on Photosynthesis of Banana Leaves

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In 1955, Guyot and Cuillé (1955) introduced a revolutionary method to control Cercospora leaf spot (*Mycosphaerella musicola* Leach) of bananas. In the course of investigating the application of fungicides in oil these workers found that the application of petroleum oils alone, of the order of 2·1 gallons per acre, gave excellent control of the disease. Because of the simplicity of aerial application of low volumes of oil and the consequential economic advantages, the method was readily accepted in most banana-producing areas.

Part of its early success can probably be attributed to the fact that in a number of areas no satisfactory attempt had been made to control the disease; and, therefore, significant increases in fruit yields were obtained. In other areas, however, where good disease control had been maintained through the use of Bordeaux mixture, the question became one of being able to maintain maximum fruit yields while using petroleum oil sprays. Studies with other crops (Hoffman, 1935; Riehl and Wedding, 1959; Schroeder, 1936) and subsequent field observations with bananas subjected to oil sprays in comparison with Bordeaux mixture indicated oil toxicity with resultant reduction in fruit yields (Dickson *et al.*, 1960).

Investigations have been initiated in this laboratory to determine the influence of oils on the physiology of the banana plant. The present report describes results of experiments concerning the influence of petroleum oil and Bordeaux mixture on photosynthesis.

Materials and Methods

Standard manometric techniques have been used throughout (Umbreit *et al.*, 1957). The studies were carried out on an illuminated Bronwill rotary Warburg apparatus. One 40 W incandescent bulb per flask provided approximately 2 000 f.c. of light at the bottom of each flask.

Leaves from commercially grown *Musa acuminata* Variety ' Gros Michel ' were utilized as a source of plant material. Leaf discs 1 cm in diameter were cut parallel to the lateral veins from alternating control and sprayed areas. All discs were cut from the same half of a leaf. Five discs were placed in each double side-arm flask (dry) with the lower surface down.

Constant carbon dioxide concentrations of approximately 0·5 per cent, except where otherwise noted, were maintained by use of Pardee's buffer (Pardee, 1949) as modified by Krebs (1951). The flasks were shaken at a rate of 107 cycles per minute at an amplitude of 2·5 cm. The water bath was maintained at 35°C.

* A subsidiary of United Fruit Co.

Respiration and apparent photosynthesis were measured as microlitres of oxygen absorbed or liberated, respectively, per 5 leaf discs per 30-minute period. True photosynthesis was estimated by correcting for concomitant post- and pre-illumination periods of respiration. A period of 15 minutes was allowed for attainment of equilibrium immediately following the light period.

Oil-treated material was obtained either from the field immediately after a typical spray operation by helicopter, or by applying oil to leaves in the laboratory by means of a modified spray tower (TEN HOUTEN and KRAAK, 1949) equipped with a De Vilbiss atomizing nozzle. The amount of oil deposited on the upper leaf surface was determined by assuming that it was equivalent to that amount deposited upon weighed aluminium paper. In the field the amount of oil deposited was determined only in the vicinity of the sample.

Table 1. Specifications of spray oil

A.P.I. gravity 60°F	30·7	*Neutralization value*	0·02
Flash point, open cup	345°F	*Viscosity, S.U. 100°F, sec*	74·8
Fire point, open cup	380°F	*Unsulphonated residue*	93·4
Aniline point	193	*Base*	*Paraffinic*

The paraffin base oil applied was typical of that in current use for disease control. The analysis is shown in *Table 1*.

RESULTS

The concentration of carbon dioxide in the flasks greatly influenced the apparent amount of inhibition of photosynthesis resulting from the application of petroleum oil to leaves (*Table 2*). The data in *Table 2* show that inhibition of photosynthesis is apparent only at low concentrations of carbon dioxide. As the concentration of carbon dioxide reaches the 3·0 per cent level the amount of photosynthesis of oil-sprayed discs approaches that of controls. On the basis of these results all experiments were conducted at a concentration of approximately 0·5 per cent carbon dioxide.

Table 2. Effect of CO_2 concentration on true photosynthesis of oil-sprayed and non-sprayed leaves*

% CO_2	*Sprayed*	*µl O_2/30 min per 5 discs*	% *Non-sprayed control*
3·0	*No*	175·9 ± 15·5	100
3·0	*Yes*	178·1 ± 10·3	101
1·0	*No*	179·4 ± 5·7	100
1·0	*Yes*	159·1 ± 4·2	89†
0·5	*No*	149·3 ± 15·9	100
0·5	*Yes*	105·8 ± 17·9	71†
0·25	*No*	126·1 ± 15·9	100
0·25	*Yes*	99·0 ± 5·5	78†

* Oil applied in laboratory: 184 ± µg/cm².
† Significant at 5 per cent probability level.

The effect of laboratory applications of various levels of petroleum oil on true photosynthesis of banana leaves is shown in *Table 3*. The table includes data from three separate experiments selected as representative of the results obtained from a dozen or more studies conducted to date. The appli-

cation of petroleum oil significantly inhibited photosynthesis; and, though less significant, inhibition increased with increasing levels of oil.

Table 3. Influence of oil deposit on true photosynthesis of banana leaves*

Treatment	μl O_2/30 min per 5 discs	% of control
No oil	140·1 ± 2·9	100
Oil: 105 ± 3·7 $\mu g/1$ cm²	118·4 ± 3·3	84†
Oil: 231 ± 2·4 $\mu g/1$ cm²	109·3 ± 3·6	78†
No oil	149·1 ± 9·1	100
Oil: 106 ± $\mu g/1$ cm²	118·3 ± 6·9	79†
Oil: 241 ± $\mu g/1$ cm²	104·3 ± 7·5	70†
No oil	102·4 ± 6·0	100
Oil: 109 ± 4·4 $\mu g/1$ cm²	58·8 ± 14·5	57†

* Oil applied in laboratory.
† Significant at 5 per cent probability level.

Since the amount of oil necessary for controlling disease is so minute, of the order of 1·0 to 1·5 gallons per acre, it was deemed essential to determine whether inhibition of photosynthesis actually occurs from field applications. Sections of leaves were collected immediately before and after a typical helicopter spray application and their photosynthetic ability was compared (*Table 4*). The oil applied, which amounted to 84±13 $\mu g/1$ cm² of upper leaf surface, reduced photosynthetic ability by 15 per cent.

Table 4. Influence of field application of oil on true photosynthesis of banana leaves*

Treatment	μl O_2/30 min per 5 discs	% of control
Control	151·6 ± 7·2	100
Oil sprayed	129·6 ± 8·2	85†

* Application by helicopter at 84 ± 13 $\mu g/1$ cm² of upper leaf surface.
† Significant at 5 per cent probability level.

The results of experiments conducted to determine the influence of Bordeaux mixture, 8–7·5–100, on photosynthesis for comparison of its effects with those of oil are shown in *Table 5*. No significant difference occurred between the control and Bordeaux. The plant material for these experiments was obtained directly from the field, and the experiments have been repeated a number of times with similar results.

Table 5. Influence of field application of Bordeaux mixture on true photosynthesis of banana leaves

Treatment	μl O_2/30 min per 5 discs	% of control
Control	113·3 ± 6·2	100
Bordeaux	110·1 ± 4·2	97*
Control	121·5 ± 10·5	100
Bordeaux	134·9 ± 13·6	111*
Control	100·8 ± 8·2	100
Bordeaux	92·3 ± 10·6	91*

* Not significant.

DISCUSSION

In general, the results presented here corroborate the findings of other investigators (HOFFMAN, 1935; KNIGHT *et al.*, 1929; MINSHALL and HELSON, 1949; RIEHL and WEDDING, 1959; SCHROEDER, 1936) in that petroleum oil inhibits photosynthesis. The magnitude of inhibition appears to depend upon the amount of oil deposited.

The fact that inhibition can apparently be decreased by increasing the concentration of carbon dioxide supports the hypothesis proposed by RIEHL and WEDDING (1959) that inhibition results from interference with gaseous exchange by the oil. Furthermore, it indicates that the phenomenon of solubilization as proposed by VAN OVERBEEK and BLONDEAU (1954) to explain the mode of action of phytotoxic oils, is probably inoperative at the levels of oils used in these experiments. This is in agreement with the results of VAN OVERBEEK and BLONDEAU (1954) and of RIEHL and WEDDING (1959) who found that little or no solubilization would occur with molecules as large as those of foliage spray oils.

From the standpoint of controlling Cercospora leaf spot of bananas, the results indicate that one might anticipate a decrease in fruit yield upon the substitution of petroleum oil for Bordeaux mixture. That this is precisely so has recently been confirmed by field data to be published (DICKSON *et al.*, 1960).

Of additional interest to the initial photosynthesis inhibition will be the recovery time as discussed by RIEHL and WEDDING (1959) for citrus and the relationship of inhibition to the mechanism of oil action on the fungus. These aspects are now being investigated.

Although the above evidence appears prejudicial against the continued use of petroleum oil for controlling Sigatoka disease, it is insufficient to justify its abandonment. First, in the studies of CALPOUZOS *et al.* (1960), the amount of oil utilized was two to three times in excess of the amount necessary to control the disease. As pointed out in these experiments, the quantity of oil bears a direct relationship to plant injury; consequently one would anticipate less injury with less oil. Secondly, the significance of the depression of photosynthesis is not fully understood since other commonly known external and internal factors contribute to as great or even greater depression.

It should also be mentioned, in regard to results from field experiments and the early use of oil in the field, that the detrimental effects generally attributed to oil might have resulted from its indiscriminate use. It was pointed out by GUYOT and CUILLÉ (1956) as early as 1956, and later by CALPOUZOS (1958), that the action of oil on the fungus was considerably different from that of Bordeaux mixture. Yet, oil was applied on the same two-week cycles as Bordeaux. Since it has recently been shown (KLEIN, 1960) that oil cycles can be greatly extended when based upon the life cycle of the fungus, one can unequivocally state that a great deal of oil has been applied to plants unnecessarily and possibly detrimentally.

SUMMARY

The influence of petroleum oil and Bordeaux mixture on photosynthesis of banana leaves has been studied using an illuminated Warburg apparatus.

The application of petroleum oil inhibited photosynthesis; the magnitude of inhibition appeared to depend upon the amount of oil deposited. The inhibition can apparently be decreased by increasing the concentration of carbon dioxide.

The data suggest that substitution of petroleum oil for Bordeaux mixture as a fungicide will result in a decrease in fruit yield.

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Premature Yellowing of Lacatan Bananas

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Premature yellowing of the leaves as a banana disorder was first reported in Lacatan bananas growing at Woodstock in Jamaica in 1953 (Banana Board Research Dept, Jamaica, 1956–58). Its occurrence was associated with conditions of low soil potash and often also with unsatisfactory moisture relations.

Exploratory trials conducted by the Banana Board Research Department (BBRD, 1956–58), indicated that premature yellowing could be reduced by potash fertilizing and that the disorder became more apparent when the plants were dressed with nitrogen fertilizer, particularly in the form of nitrate.

Symptoms resembling premature yellowing were observed for the first time in an area of 350 acres, consisting of young volcanic soils, at Ekona, situated on the eastern slopes of the Cameroon mountain. The land, previously planted with Gros Michel bananas but abandoned owing to Panama disease, was replanted with Lacatan bananas in May 1959. Leaf samples taken in this area were chemically analysed on their potash content and compared with samples taken in a fertilizer experiment, situated in the same area and also replanted with Lacatan bananas in May 1959.

METHODS

(1) *Fertilizer experiment*

The Lacatan fertilizer trial was of a randomized block design with six treatments in four replications. Each plot of 72 plants was surrounded by a single guard row, the planting density being 512 plants per acre. The six (nitrogen–phosphorus—potassium) treatments were: 1N. 1P. 1K, 1N. 1P. 2K, 1N. 1P. 3K, 2N. 1P. 1K, 2N. 1P. 2K, and 2N. 1P. 3K, consisting of the following amounts of fertilizer applied in two equal amounts before and after the rains respectively:

1N = 300 lb/acre per annum sulphate of ammonia
2N = 600 lb/acre per annum sulphate of ammonia
1P = 400 lb/acre per annum superphosphate
1K = 300 lb/acre per annum muriate of potash (50%)
2K = 600 lb/acre per annum muriate of potash (50%)
3K = 900 lb/acre per annum muriate of potash (50%)

(2) *Leaf analysis*

Premature yellowing of the Lacatan bananas planted at Ekona was first observed in the beginning of January 1960, eight months after planting. Owing to severe infestation with parasitic eelworms (Price, 1960), growth of the bananas had been very irregular. In terms of the arbitrary categories chosen by the BBRD (1956–58) for defining different stages of growth, the

plants at sampling in January 1960 occurred both in stage II—from the shedding of the last pointed leaf until two thirds grown—and stage III—two thirds grown to emergence of the inflorescence.

Growth was much more uniform in the fertilizer trial, probably owing to an overall application of a nematicide* (PRICE, 1960) in October 1959, the majority of the plants having reached stage III.

Bulk leaf samples were taken monthly from the youngest fully opened leaf of 25 plants chosen at random in each of the 24 experimental plots of the fertilizer trial. The analytical results of the potash contents of the leaves sampled at the end of January 1960 were compared with the leaf potassium contents of samples taken in the plantation bananas at the beginning of February 1960. The latter received one dressing only of 4 cwt/acre of an NPK compound fertilizer (10–9–29) at the end of the rains in October 1959.

Three bulk leaf samples were taken from 20 plantation plants, chosen at random. One bulk leaf sample was taken from the youngest fully opened leaf, one from the fourth or fifth leaf showing the premature yellowing disorder, and one from the fifth or sixth green leaf, not showing premature yellowing.

Leaf sampling consisted of cutting off pieces of leaves about 4 in. wide from either side of the midrib in the middle part of the leaf. Sampling was done before 9 a.m. and completed in one day. The samples were analysed in accordance with the methods described by BROESHART (1955).

The observations referred to in the text cover the period January to March (inclusive) 1960, which is the driest part of the year.

RESULTS AND DISCUSSION

The loamy clay soils at Ekona consist of dark brown young volcanic ash deposits, well drained, rich in organic matter (on the average approximately 2·7 per cent in the top 60 cm and 2·0 per cent between 60 and 100 cm) and in nutrients, and with a pH varying between 5·5 and 6·5.

Generally, volcanic ash of basic parent rock is relatively poor in potash-bearing minerals (MOHR and VAN BAREN, 1954), resulting in a low potash content on total chemical analysis.

In the Cameroons, large responses from potash fertilizing were obtained in numerous trials, not only in bananas, known for their large potash requirements (SIMMONDS, 1959), but also in oil palms (HASSELO, 1959) and even in rubber.

In *Table 1*, the effect is shown of increasing nitrogen and/or potash dressings on bunch weight of Gros Michel bananas in the period 1955–58, i.e. before the same site was replanted with Lacatan bananas in May 1959. Significant effects of increased potash dressings (both as a treatment and its main effect) were consistently obtained. Extra nitrogen dressings did not increase bunch weights nor the rate of growth, unless combined with larger potash dressings. On several occasions positive interactions between nitrogen and potash were obtained, the optimal ratio between nitrogen and potassium oxide varying between 1 : 3 and 1 : 5. Marked potash deficiency symptoms,

*Nemagon: Shell Trade Mark for a 1,2-dibromo-3-chloropropane formulation.

Table 1. Gros Michel: mean bunch weight (kg, full grade)
(Mean of 4 replications)

Treatments	1955 (plant crop) (last 2 quarters only)	1956	1957	1958		
				1st quarter	4th quarter	Year
1N. 1P. 1K	29·00	33·75	29·50	33·75	33·50	32·25
1N. 1P. 2K	31·75	35·25	31·50	33·25	34·00	33·50
1N. 1P. 3K	31·00	33·50	31·00	34·00	37·25	33·00
2N. 1P. 1K	28·25	30·25	29·00	27·00	33·75	29·50
2N. 1P. 2K	30·25	37·00	31·75	33·75	41·75	33·75
2N. 1P. 3K	31·75	35·50	33·25	36·25	43·25	36·00

as described by MURRAY (1959), could not, however, be assessed with certainty in this trial, nor in other trials with Gros Michel bananas, where responses in bunch weight to potash fertilizing were obtained of the order of 30 per cent and more.

Quite a different picture was obtained when these soils were replanted with Lacatan bananas. Symptoms of premature yellowing were observed eight months after planting. They were similar to those described by SIMMONDS (1959) and MURRAY (1959): ' the older leaves turn yellow at the tips and distal margins and the yellowing very rapidly spreads in a proximal direction until the whole leaf has withered ', and ' not infrequently, one or two leaves in the middle of the crown are affected, being separated from the affected bottom leaves by one or two healthy ones '. The latter characteristic feature was apparent in the plantation bananas, but not in the experimental area. Premature yellowing in the Lacatan fertilizer trial was observed only in the buffer rows and some of the plots receiving the double dose of nitrogen at a low potash level (treatment 2N. 1P. 1K). The symptoms were not as marked as in the plantation bananas.

Table 2. Leaf potassium oxide content (% dry matter)

Lacatan fertilizer trial

Treatment	Leaf potassium oxide content (mean of 4 replications)
1N. 1P. 1K	5·18
1N. 1P. 2K	5·65***
1N. 1P. 3K	5·48**
2N. 1P. 1K	5·10
2N. 1P. 2K	5·63***
2N. 1P. 3K	5·58**

**Significant difference at P 0·01 : 0·23.
***Significant difference at P 0·001 : 0·45.

Plantation samples

Leaf number	Leaf potassium oxide content		Mean
	Sample 1	Sample 2	
Youngest fully opened leaf	4·14	4·11	4·13
4th or 5th chlorotic leaf	4·01	4·09	4·05
5th or 6th green leaf	4·10	4·12	4·11

In order to check the relationship between premature yellowing and leaf potash content, leaf samples taken both in the plantation and in the fertilizer trial were analysed on their leaf potash content (*Table 2*).

The larger dressings of potash in the Lacatan fertilizer trial highly significantly increased the leaf potash contents. It is of interest to note that the lowest level was obtained in the 2N. 1P. 1K plots.

It would confirm (*a*) the work done in Guinea (Champion *et al.*, 1958) on the effect of ammonium sulphate on the fixing of potassium, viz. that the available amount of soil potassium decreases in the presence of ammonium sulphate, (*b*) the responses obtained (*Table 1*) from the different treatments on bunch weight of Gros Michel bananas in the period 1955–59 prior to the same area being replanted with Lacatan, and (*c*) the work done in Jamaica (BBRD, 1956–58).

It will be seen from *Table 1* (year 1958) that the most striking favourable and unfavourable effects of extra potash and nitrogen dressings respectively were obtained in the first and fourth quarters, i.e. the dry half of the year. The pronounced effect of potash in dry periods has two aspects. From physiological studies it is well known that potash, when present in sufficient concentration in the leaves, permits better control of the water economy. Secondly, in accordance with the Donnan equilibrium of soil colloidal behaviour, potash is less available in a dry soil (Schuffelen and Middelburg, 1953).

In view of all these points, it is not very surprising that premature yellowing became apparent for the first time in January, i.e. in the middle of the dry season and in the plots where the concentration of potash in the leaves was relatively low.

It will be seen from *Table 2*, that the leaf potash contents of the plantation bananas were very much lower, the chlorotic leaves with a potassium oxide-content of 4·05 per cent having the lowest concentration. On the average the plantation bananas had a 20 to 30 per cent lower potash content than those in the trial. It would appear, therefore, that premature yellowing is related to, if not caused by, a low leaf potash content, and that the critical potassium oxide level under the mitigating circumstances of soil and season was about 5·1 per cent.

One further complication in the interpretation of the results is that of the efficiency of the root system. In an experiment situated on the same soil in the same area, Price (1960) has shown nematode infection to be serious, causing considerable damage to the roots and the corm. The majority of the older roots were dead, causing a reduction in growth of the order of 25 per cent.

It would seem reasonable to assume that premature yellowing, alternatively the low leaf potash content, was induced by the inefficiency of the seriously damaged root system to take up potash from a soil with an inherently low potash availability, which was even further decreased by a low relative availability of potash in the dry season.

The characteristic feature of one or two prematurely yellowing leaves occurring in the middle of the crown and separated from the (often) affected bottom leaves by one or two healthy ones, was, as stated previously, observed in the plantation bananas but not in the 2N. 1P. 1K plots of the fertilizer

trial. It would seem to indicate some disorder in the translocation of potassium ions from the older, but healthy and green leaves (cf. the fifth and/or sixth green leaf of *Table 2*) between the oldest affected and younger chlorotic leaves. For one would normally expect the process of translocation of these ions under conditions of lack of potash to progress regularly with decreasing age of the leaves, causing premature senescence of the leaves as with Gros Michel bananas under similar conditions.

It is tempting to relate this extremely characteristic feature to root and corm damage by nematodes or rather that particular part of it, which is connected with the healthy fifth or sixth leaves, thereby obstructing the translocation of potash to the younger developing leaves. Bananas are monocotelydonous and the analogy with vascular wilt diseased oil palms in the Cameroons is striking to the extent that, when a palm leaf dies in the middle of the crown, it is due to a toxin and to blocking of the vessels, which in turn are connected with that particular part of the root system, which was invaded by the fungus.

A possible explanation for the banana disorder would be that owing to damage to the tissues of the corm (' black head ' condition) the connection between the green fifth and sixth leaves and the developing leaves was blocked, thus preventing the translocation of potassium ions.

There were several indications to favour this hypothesis:

(*1*). Lacatan bananas are less tolerant to eelworms than Gros Michel—this would explain why prematurely yellowing leaves in the middle of the crown have never been observed in the latter.

(*2*). The potassium oxide content of the fifth and sixth green leaf (4·11 per cent) (cf. *Table 2*) was well below the level at which premature yellowing began to appear in the Lacatan fertilizer trial (5·10 per cent). The latter area, however, was treated with a nematicide and therefore should not have suffered to the same extent from eelworm damage, as a result of which premature yellowing was confined to the older leaves, progressing regularly with increasing age of the leaves.

(*3*). It was observed that the process of premature yellowing of the fourth or fifth leaf did not attain its ultimate stage, i.e. the complete withering of the leaf. It stopped at the stage where the marginal yellowing became necrotic, the proximal part of the leaf remaining green. In this context, it could have been due to eelworm damage blocking further translocation of the potassium ions, thus preventing the complete withering of the leaf. The latter process repeated itself on several occasions in the next younger leaf, but could not be followed further because of the bananas receiving their next half annual fertilizer application.

To summarize, it would seem possible that the irregular pattern in the occurrence of premature yellowing of the leaves, viz. that some of the older leaves were not affected, is related to the rate at which eelworm damage progresses. If it progresses faster than the translocation of potash from the older to the developing leaves, the translocation may come to a sudden standstill and before the ultimate stage of complete withering of the leaf has been attained.

More conclusive evidence is required to confirm the relationship. This preliminary study might, however, have served the purpose of showing

some aspects of the complex nature of premature yellowing in its relation to the potash status of the soil and within the leaves in different seasons and the efficiency of the root system under conditions of eelworm infection.

SUMMARY

The occurrence of premature yellowing in eight to ten months old Lacatan bananas, growing on potash-deficient soils in an area heavily infested with eelworms, was discussed in relation to the potash content of the leaves in the dry season.

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Note on the Reversion of the Dwarf Banana 'Cocos' to 'Gros Michel'

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The mutation of genes controlling plant height in bananas is of common occurrence. Simmonds [Simmonds, N. W. (1959). *Bananas.* Longmans, Green: London, 466 pp] lists nine varieties for which dwarf counterparts have arisen by somatic mutation. The mutation of the 'Gros Michel' variety to a dwarf form has occurred in Jamaica ('Highgate'), Panama ('Cocos') and Honduras ('Omonita dwarf'). In addition, several other probable cases remain unchecked. Since 1956 widespread propagation of the 'Cocos' variety in Honduras has allowed the careful observation of large populations. As might be expected, occasional tall reversions have appeared.

Mutations usually occur in low frequencies, and are commonly confused with contaminations. In sexually reproducing plants a stray pollen grain can contaminate, and precautions must be taken to prevent the confounding of mutations with events of this type. This is no less true in vegetatively reproducing organisms like the commercial banana where a foreign seed bit in a newly planted field could be mistaken for a mutant. The obvious and unquestioned proof of a somatic mutational event in this case is to observe the rhizomatous connection between the parent plant and its mutant progeny. To the author's knowledge, this precaution was not observed in the dwarf mutants of 'Gros Michel' mentioned above.

The somatic mutation to be reported here was first observed by a sharp-eyed agricultural worker several weeks before the 'Cocos' parent produced marketable fruit and was destroyed. *Figure 1* shows this unique mat with its 'Cocos' plant producing a tall, slender sucker. Since the tissue connecting these two shoots was observed, there can be no doubt about the origin of the sucker. This mutant illustrates the 'Gros Michel' morphological features: erect shoot, tall slender pseudostem which is not bulbous, and long, slender leaves loosely spaced at the crown. For comparative purposes, a 'Cocos' parent with a typical 'Cocos' sucker in the same stage of development is included (*Figure 2*). The 'Cocos' sucker has a leaning shoot, a short stout pseudostem, bulbous at the base, and short, broad leaves closely spaced at the crown. *Table 1* summarizes data on leaf shape (probably the best single criterion for distinguishing degree of dwarfing in bananas) for the varieties 'Gros Michel' and 'Cocos' as well as the unique plant in question. These data clearly place the mutant sucker as 'Gros Michel'.

* A subsidiary of United Fruit Co.

Figure 1. ' Cocos ' mat producing a ' Gros Michel ' sucker

The differences between ' Cocos ' and ' Gros Michel ' can be explained by the foreshortening of plant parts. The changes between tall and short plants are reversible and occur in substantial numbers. Most important, the sexual progeny of the dwarf types when pollinated by tall types is of short stature. For these reasons, changes from the tall ' Gros Michel ' to the short ' Cocos ' are undoubtedly controlled by gene mutation. The gene

Table 1. Leaf shape in ' Cocos ' and ' Gros Michel ' as measured by the ratio of width to length

Variety	*Parent*		*Sucker*	
	Observations (number)	*Leaf ratio (width/length)*	*Observations (number)*	*Leaf ratio (width/length)*
Cocos	27	0·377	24	0·369
Gros Michel	26	0·283	23	0·284
Cocos with Gros Michel sucker	11	0·354	8	0·272

Figure 2. 'Cocos' mat producing a typical 'Cocos' sucker

involved controls length of plant parts and mutates to a dominant allele which produces shortened parts.

The changes from short to tall plants are considerably more frequent than the original mutation. (From 50 to 70 tall reversions have appeared among about 28 000 'Cocos' mats over a three-year period.) It is likely, therefore, that this change is controlled by the somatic loss of the dominant dwarfing allele rather than by reverse gene mutation.

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Productivity of Pasture in British Honduras—II

Pangola Pasture (As influenced by climate, soil type and phosphate fertilizer)

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Initial work (Romney, 1960) has indicated the low yield, poor botanical composition and negligible response to fertilizers of natural pasture in the western district of British Honduras. Subsequent studies were consequently confined to improved pastures, and were designed to characterize the productivity of an established sward over the course of twelve months or more.

SOILS

The mean annual rainfall in British Honduras ranges from 50 in. in the north to 180 in. in the south. Soils vary from shallow clays over chalk to deep alluvials. Seven experiments of similar design were laid down as shown in *Table 1* using Pangola grass (*Digitaria decumbens*). These soils were chosen because they are all agriculturally important and extensive; they together constitute 300 000 acres or 12 per cent of the total area of soil in the Territory suitable for agriculture (Wright *et al.*, 1960).

Table 1

District	*Longitude*	*Latitude*	*Rainfall in.*	*Soil type*
Northern	88°29′W	18°20′N	50	*Xaibe clay loam*
Northern	88°30′W	18°18′N	50	*Louisville clay*
Northern	88°35′W	18° 5′N	60	*Pixoy sandy loam*
Belize	88°25′W	17°30′N	80	*Puletan loamy sand*
Western	89° 0′W	17°10′N	50	*Barton silty clay loam*
Stann Creek	88°20′W	17° 0′N	90	*Melinda silty clay*
Stann Creek	88°25′W	17° 0′N	110	*Stopper coarse sandy clay*

Available phosphate was determined by extracting with 0·002N sulphuric acid containing 3 g ammonium sulphate per litre. Available potash was determined by extracting with 3 per cent acetic acid. The pH was measured electrometrically using a soil:water ratio of 1:5 (see *Table 2*).

ESTABLISHMENT

The general mode of establishment of Pangola grass in British Honduras is to spread the cuttings on land prepared mechanically and then disc them in. A 2,4-D spray is usually given after about four weeks to kill annual weeds.

* Present address: Coconut Industry Board, Kingston, Jamaica.

Table 2

Soil type	*Profile*	pH	*O.M. per cent*	*Available nutrients (p.p.m.)*	
				P_2O_5	K_2O
Xaibe clay loam	*3 in. brownish-red clay loam*	7·3	8·7	40	1 296
	3–6 in. red clay with some limestone gravel	6·6	2·6	19	595
	on pale pink chalk and limestone				
Louisville clay	*3 in. black crumbly clay*	7·8	6·2	39	413
	6–9 in. black clay	7·3	1·8	8	215
	on white chalk				
Pixoy sandy loam	*9 in. black sandy loam*	6·7	5·0	50	135
	12–20 in. red, yellow and grey mottled sandy clay	6·8	1·0	10	75
	on white sandy chalk				
Puletan loamy sand	*4 in. pale grey loamy sand*	5·2	5·7	9	106
	1 in. dull yellow sandy clay loam	4·8	0·2	7	51
	on red, yellow and grey mottled stiff sandy clay becoming pale grey at depth				
Barton silty clay loam	*4 in. brown silty clay loam*	6·2	4·7	28	155
	4 in. pale brown silty clay loam	6·3	1·5	37	86
	6–9 in. grey-brown silty clay with manganese nodules	6·2		26	79
	on brown-grey mottled silty clay				
Melinda silty clay	*4 in. grey-brown silty clay*	4·5	7·9	38	169
	6–12 in. pale brown silty clay	4·5	2·2	7	59
	on pale brown-grey compact silty clay, mottled red and yellow	4·8	0·7	7	70
Stopper coarse sandy clay	*3 in. crumbly dark brown coarse sandy clay*	5·6	4·8	25	316
	6–9 in. brown coarse sandy clay	5·5	0·8	8	79
	on vermilion stiff coarse sandy clay	5·3		0	70
	over granite				

The pasture is then left at least four months to allow the Pangola to smother other plants. One acre of established Pangola pasture will furnish enough cuttings to plant 10 to 15 acres. The experiments here reported were often on sites inaccessible to tractors. The areas were cleared of weeds and low bush with a cutlass, shallow furrows made about 3 ft apart with a hoe and the cuttings planted and covered by hand. Good

drainage is necessary (Blaser *et al.*, 1945), especially to enable the Pangola grass to overcome sour grass (*Paspalum virgatum*) during the establishment phase. Fertilizer is not necessary at planting time, except on very infertile soils to speed up growth and assist competition with weeds.

Pangola grass has three serious disadvantages. In many parts of British Honduras it is badly attacked by Froghopper insects (*Aeneolamia* sp.) and requires insecticidal dusting or spraying during June or July, usually with 40 per cent Aldrin at 2 lb/acre. Secondly, although growth is very vigorous in the first 6 to 12 months after planting, it then slows up visibly: some farmers have described it as being ' root-bound '. Thirdly, it appears to require heavy feeding with nitrogenous fertilizer: this latter fact may be the real reason for its becoming ' root-bound '.

EXPERIMENTAL LAYOUT

As phosphate is notoriously deficient in most soils in British Honduras, the treatments shown in *Table 3* were used. Plots were 1/200 acre each and there were four replicates, i.e. a total of 20 plots, at each site. The established Pangola grass was given a general dressing of 100 lb/acre of muriate of potash (60 per cent K_2O) at the beginning of the experiments. The phosphate was also applied at the beginning of the experiments. Previous work had shown that clipping intervals of 21 days were too short, the sward being eliminated in patches and replaced by *Axonopus compressus* (known locally as ' crab grass '). A uniform interval of six weeks was therefore chosen and found to be very satisfactory, the sward being in a stage suitable for grazing, although in the dry season the interval was occasionally lengthened to seven weeks. A dressing of 50 lb/acre of sulphate of ammonia (21 per cent nitrogen) was given immediately after each clipping, i.e. 400 lb/acre per annum. This fertilizer, after weighing, was sometimes mixed with an approximately equal quantity of sawdust to facilitate more even application.

Table 3

Treatment	A	B	C	D	E
Triple super (46% P_2O_5) *lb/acre*	0	100	200	400	800

A light Land-Rover windscreen frame was used to throw into each plot, the area within it was cut with a cutlass at a height of one to two inches, and the fresh weight recorded. This frame was later replaced by a collapsible wooden frame of the same dimensions (57 in. by 17 in., i.e. 0·748 square yard) which could be carried on a motor-cycle to the more remote sites (up to 170 miles away). The fresh material was sub-sampled by 'grabbing' one sample of 5 to 10 grammes from each plot, the samples being put into plastic bags and brought to the laboratory for dry matter and crude protein determinations.

YIELDS

The total annual yields of dry matter (D.M.) from high phosphate dressings were usually slightly more than from low phosphate dressings or the control treatment and, on all sites except two, the lower phosphate

dressings gave a greater yield than the control (see *Tables 3* and *4*). None of these yield responses to phosphate was statistically significant, however, even though most of the soils respond markedly to phosphate with other crops, viz., sugar-cane on Xaibe and Louisville soils, corn on Stopper and Puletan soils.

Table 4

Soil type	*Yield (lb D.M./acre per annum × 10⁻²)*					
	Treatment:					
	A	*B*	*C*	*D*	*E*	*Mean*
Xaibe	154	158	182	189	188	174
Louisville	172	208	208	198	212	200
Pixoy	233	242	232	209	253	234
Puletan	105	127	119	122	141	123
Barton	196	219	230	215	224	217
Melinda	213	207	256	267	286	246
Stopper	220	245	229	279	258	246

Table 5

Soil type	*Duration of experiment*		
	Commencing	*Ending*	*Total weeks*
Xaibe	6.7.57	26.6.58	51
Louisville	24.10.56	25.6.58	87
Pixoy	17.12.56	27.9.58	90
Puletan	5.10.56	6.3.58	73
Barton	11.9.56	5.3.58	76
Melinda	21.6.57	9.9.58	62
Stopper	4.7.56	9.10.58	120

There would not appear, on the basis of these somewhat variable results, to be any appreciable advantage in the higher levels of phosphate application. *Table 6* gives the mean percentage increases over control in yield of dry matter due to the four phosphate applications.

Table 6

Soil type	*Yield of D.M. (percentage increase over control)*
Xaibe	16
Louisville	20
Pixoy	1
Puletan	21
Barton	13
Melinda	19
Stopper	13
Overall mean	15

YIELD CURVES

Figures 1, *2* and *3* show the seasonal distribution of yield of dry matter from Pangola grass on Xaibe, Louisville, Barton, Stopper and Melinda soils, together with the corresponding rainfall and temperature measurements. Data for Pixoy and Puletan soils were not detailed enough to permit construction of a curve. Each point on the yield curves is the average of

20 plots. The letters along the abscissae represent the months of the year, and their position indicates the middle of the month. Yields are measured at the end of every six weeks but are plotted to correspond with the middle of that period. Similarly, monthly rainfall is plotted to correspond with the middle of the month.

It is evident that the yield of Pangola grass in the Northern District (Xaibe and Louisville soils) varies in proportion to the rainfall (Xaibe and Louisville experience about the same rainfall). The *maugre* or ' little dry ' season of August reduces growth a little, particularly at Xaibe where the soil is shallow and droughty.

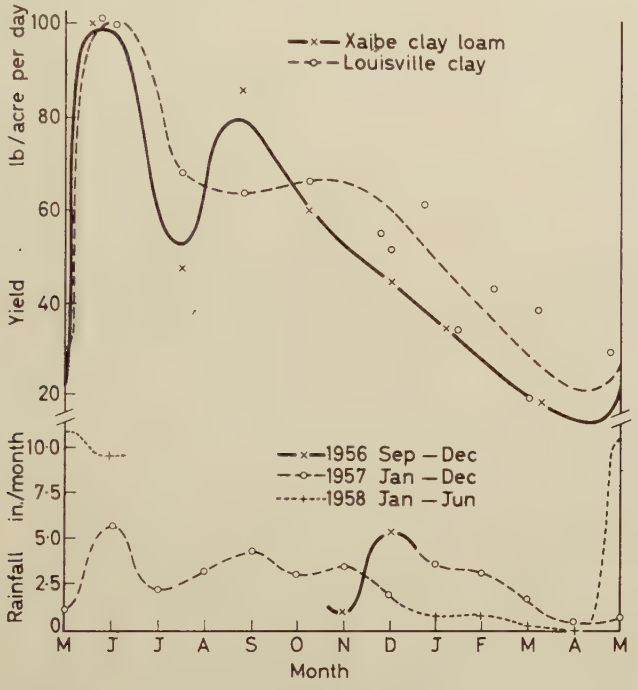

Figure 1. Yield of Pangola pasture on Xaibe and Louisville soils (in lb D.M./acre per day), and rainfall at Louisville (in in./month)

It would appear that Pangola grass on Barton soil in the Western District undergoes a lull in its growth during the short days and low night temperatures of November, December and January. The yield in March, April and May, when monthly rainfall is less than 4 in., is not noticeably retarded.

The total annual production is greatest on Stopper and Melinda soils, where mean annual rainfall is around 100 in. As on the Barton soil, the main deterrent to growth appears to be the cool weather and short days from November to January.

DRY MATTER CONTENT

Table 7 shows some increase in per cent dry matter during the height of the dry season (the gaps in the table occur because harvesting was done

every six weeks). The overall mean dry matter was 33 per cent. The yields and yield curves, being based upon dry matter, do not fully reveal the reduced *fresh* matter yield during the dry season and, presumably, a reduced palatability. The dry matter content is not unlike that of guinea and jaragua grasses undergoing similar experiments, viz.

Pangola grass (*Digitaria decumbens*)	33% D.M.
Guinea grass (*Panicum maximum*)	36% D.M.
Jaragua grass (*Hyparrhenia rufa*)	35% D.M.
Sweet grass (*Ixophorus unisetus*)	17% D.M.

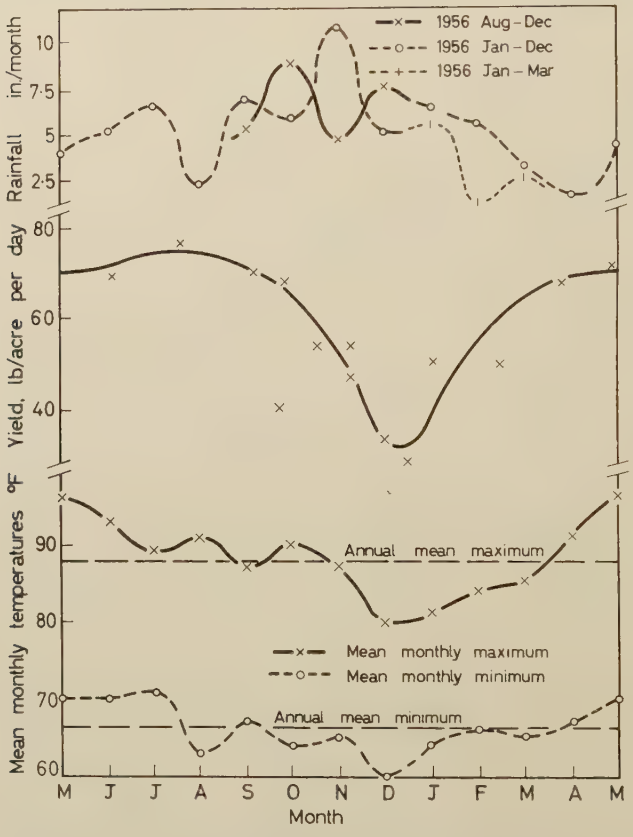

Figure 2. Yield of a Pangola pasture on Barton silty clay loam (in lb D.M./acre per day), mean monthly maximum and minimum temperatures at Central Farm during 1957, and rainfall at Central Farm (in in./month)

PROTEIN CONTENT

Table 8 gives the crude protein content of Pangola grass on Barton silty clay loam. The determinations were done, following a Kjeldahl digestion, by distillation from a Markham apparatus into boric acid containing screened methyl orange indicator.

The reduced yield in November, December and January is parallelled by an increase in crude protein content. The mean annual content of crude protein in the dry matter (6·3 per cent) is only moderately high considering

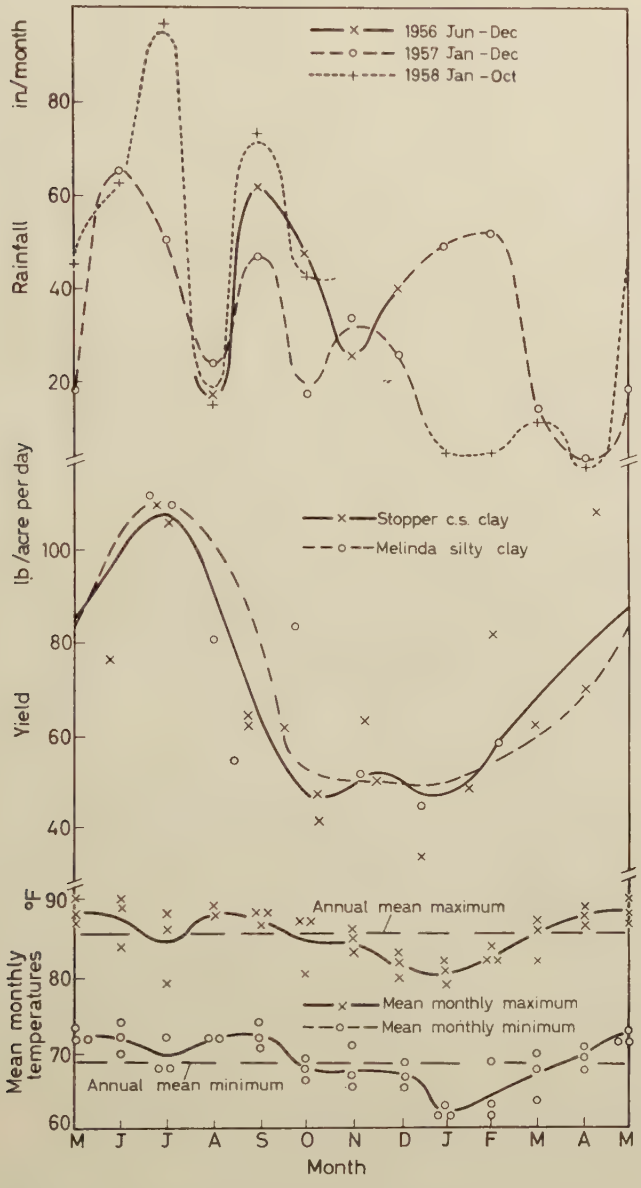

Figure 3. Yield of Pangola pasture on Stopper and Melinda soils (in lb D.M./acre per day), mean monthly maximum and minimum temperatures at Stann Creek Agricultural Station during 1956–58, and rainfall at Alta Vista (in in./month)

that these experimental areas received regular nitrogen dressings totalling 80 lb nitrogen per annum. Unfertilized guinea and jaragua grasses in the same area have been analysed at 7·2 per cent and 5·2 per cent mean crude protein in the dry matter respectively.

Table 7. Per cent dry matter in Pangola grass

Soil	Month											
	M	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*
Xaibe		32	30	27		25	33		34	35		36
Louisville	41	23	32	33		26	31	25	29	37	33	36
Pixoy	59		32			24	35	27				30
Puletan			33	34		37		35		27	44	
Barton		49	26	38		29		25	15	23	33	50
Melinda		35		25	26	26		23	20		47	
Stopper	64	31		25	22	29		24	41	25	35	30

Table 8. Crude protein (per cent in D.M.)

Treatment *Triple super* (*lb/acre*)	*A* 0	*B* 100	*C* 200	*D* 400	*E* 800	*Mean*
Harvest date						
15.4.57	7·4	4·6	6·1	5·7	5·1	5·8
4.6.57	4·4	3·5	3·4	4·1	3·0	3·7
16.7.57	4·9	5·0	5·0	4·8	3·8	4·7
26.8.57	5·5	3·5	4·3	4·3	6·5	4·8
31.10.57	5·5	4·9	6·4	5·3	6·6	5·7
12.12.57	10·6	8·8	9·9	8·3	6·1	8·7
22.1.58	8·2	8·2	11·1	9·2	8·7	9·1
5.3.58	7·6	8·5	6·2	7·4	8·8	7·7

Table 9

Soil type	*Theoretical cattle holding capacity* (*beasts per acre*)		
	Dry season (*Jan–May*)	*Wet season* (*Jun–Dec*)	*Annual mean*
Xaibe	0·6	1·8	1·3
Louisville	0·8	1·8	1·5
	Cool season (*Nov–Jan*)	*Hot season* (*Feb–Oct*)	
Barton	1·2	2·0	1·6
Stopper	1·4	2·1	1·8
Melinda	1·4	2·1	1·8

DISCUSSION

It is evident from *Tables 2* and *4* that the annual yield of dry matter is not related to soil pH. Neither was there any significant response to phosphate. The lowest yields occur on the Puletan soil, which tends to be droughty and phosphate-deficient and also suffers from temporary water-logging after heavy rain.

The nitrogen treatments were the same on all plots, viz. 400 lb/acre of sulphate of ammonia per annum. The mean annual production of dry matter on the seven sites was 20 600 lb/acre. For comparison (Oakes *et al.*, 1959), Pangola pastures under conditions of low rainfall in the Virgin

Islands, receiving nitrogen equivalent to 600 lb/acre sulphate of ammonia, yielded 13 300 lb dry matter per acre per annum.

Assuming that the average daily dry matter intake is 25 lb per beast and that 70 per cent of the clippable grass is utilized by the grazing animal, theoretical cattle-holding capacities would be as shown in *Table 9*.

Some evidence is already to hand of marked response of Pangola grass to nitrogenous fertilizer, and further work is being conducted to assess this.

SUMMARY

The seasonal yields of fertilized Pangola grass on five sites, ranging in pH from 4·5 to 7·8 and in mean annual precipitation from 50 in. to 110 in., are presented graphically. Plots were clipped at 6-week intervals. Some relationship between yield and rainfall and temperature is demonstrated. Mean annual production of dry matter is 20 600 lb/acre. Response to phosphate is not significant. Seasonal dry matter and crude protein data are given, the mean annual values being 33 per cent and 6·3 per cent respectively.

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Direct and Residual Effects of Striga *Control Treatments on Sorghum Yields*

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Striga spp. parasitize roots and decrease yields of many tropical crops, e.g. maize, sorghum and sugar-cane. Most of the parasites remain stunted and subterranean, but a few produce aerial stems which flower and seed prolifically (Luthra, 1921; Penzhorn, 1954). Because the seeds germinate readily only when stimulated by suitable root exudates (McGrath *et al.*, 1957) and can remain viable for ten years (Saunders, 1933; Pearson, 1911), many often persist in soil and endanger future crops.

The immediate effects of trap crops, selective weedkiller sprays and fertilizers on the incidence of *Striga hermonthica* in sorghum have been described (Last, 1960a). In 1958 a site at Zeidab, Sudan, used in the previous season for testing this range of treatments, was again planted with sorghum but without repeating the treatments. From the results it was possible to assess the residual effects.

EXPERIMENTAL

The experiment of 75 plots, each 0·05 acre, was carried out on alkaline clay soils at Zeidab (Lat. 17°26′N; Long. 33°54′E) *ca.* 175 miles northeast of Khartoum. The site was planted with sorghum for many years, without fertilizer, and had become heavily infested with *S. hermonthica.*

Seeds of the locally popular, long-strawed, sorghum variety Debekri (*Sorghum vulgare* Pers, var. *durra* Stapf.), dusted at a rate of 1:450 w/w with a fungicide-insecticide mixture containing 25 per cent tetramethylthiuram disulphide and 20 per cent gamma benzene hexachloride (Tarr, 1954) were planted on the flat in September and the crops harvested in December. Groups of eight seeds were put in holes 50 cm apart, in rows 80 cm apart. Plots were irrigated at intervals of about 10 days.

In the first season, 1957, the factorial combinations of three series of treatments were applied—5 fertilizer, 5 weedkiller spray and 3 trap crop treatments (total of $5 \times 5 \times 3 = 75$ plots). In the second season their residual effects were tested.

1957 (Sorghum planted 1 Sep; harvested 20–26 Dec)

(*1*) No *weedkiller spray* versus 0·8 and 1·6 lb/acre of the sodium salt of 2,4-dichlorophenoxyacetic acid (2,4-D) sprayed either two or three weeks after sowing. At these rates and dates Wilson-Jones (1953a, 1954) found that 2,4-D delayed the emergence of *S. hermonthica* without seriously affecting sorghum growth—at higher concentrations it can be as damaging as *S. hermonthica.* 2,4-D plus dispersing agent was mixed with water and sprayed at a rate of 80 gallons/acre from a knapsack sprayer.

* Work done while seconded to Gezira Research Station, Wad Medani, Sudan.

(*2*) No *trap crop* versus Sudan grass [*Sorghum sudanense* (Piper) Stapf.]* grown for either three or five weeks before planting sorghum. Sudan grass stimulates the germination of *S. hermonthica* and is later parasitized (McGrath *et al.*, 1957).

Sudan grass seed was broadcast at a rate of 40 lb/acre on either 24 July or 7 August, the land was raked and then irrigated every ten days until 18 August. On 28 August the grass was cut at ground level—the foliage was removed but the roots were left *in situ*. Four days later the main sorghum crop was sown. Sudan grass did not regenerate.

(*3*) No *fertilizer* versus fertilizers, a mixture of 400 lb sulphate of ammonia (21 per cent nitrogen) and 200 lb superphosphate (21 per cent phosphorus pentoxide)/acre at sowing, and at three, six or nine weeks later.

1958 (Sorghum planted 4 Sep; harvested 17–23 Dec)

To ensure a sorghum crop adequate to detect residual effects from treatments applied the previous year, the entire experiment was dressed, just before planting, with 200 lb/acre of sulphate of ammonia.

Growth observations

The incidence of *S. hermonthica* was measured in two ways. Sorghum holes with aerial stems of *S. hermonthica* were counted and expressed as percentages of the total number of holes per plot equal to the percentage infection. These were not modified or ' weighted ' to allow for varying numbers of parasitic stems per hole. Secondly, *S. hermonthica*, both living and dead, was collected about three weeks before the 1957 sorghum harvest and air dried to constant weight.

The sorghum yields refer to weights of unthreshed grain and air dried straw.

Analysis of results

Because errors increased with the size of the means, most of the yields needed to be transformed before statistical analysis to log $(n+1)$, where n is the actual weight in g/plot or lb/acre. The percentage infections also needed to be transformed, but to angles. For simplicity the transformed data have usually been omitted but where given, they are in italics; actual measurements are given with asterisks marking statistically significant differences ($p=0{\cdot}05$) between treatments and their respective controls. The least significant differences given in *Figure 1* were calculated from the actual measurements.

RESULTS

(a) *Selective weedkiller sprays*

Incidence of S. hermonthica—In the first season (1957) sprays with 1 and 2 lb/acre of 2,4-D delayed the emergence of *S. hermonthica* and decreased the levels of infection equally; spraying 14 days after planting sorghum was more effective than spraying after 21 days, but not significantly so (*Figure 1*). Parallelling the decreases in the levels of infection were similar decreases

* 3 plants are frequently mentioned in the text—*Sorghum vulgare* Pers., *Sorghum sudanense* (Piper) Stapf. and *Striga hermonthica* (Del.) Benth. To avoid confusion when abbreviated, they will be referred to as sorghum, Sudan grass and *S. hermonthica* respectively.

in the weights of *S. hermonthica*. Spraying with 1 and 2 lb of 2,4-D decreased the parasitic growth from 122 in the unsprayed controls to 68 and 59 lb/acre respectively; spraying 14 and 21 days after planting decreased it from 122 to 52 and 75 lb/acre.

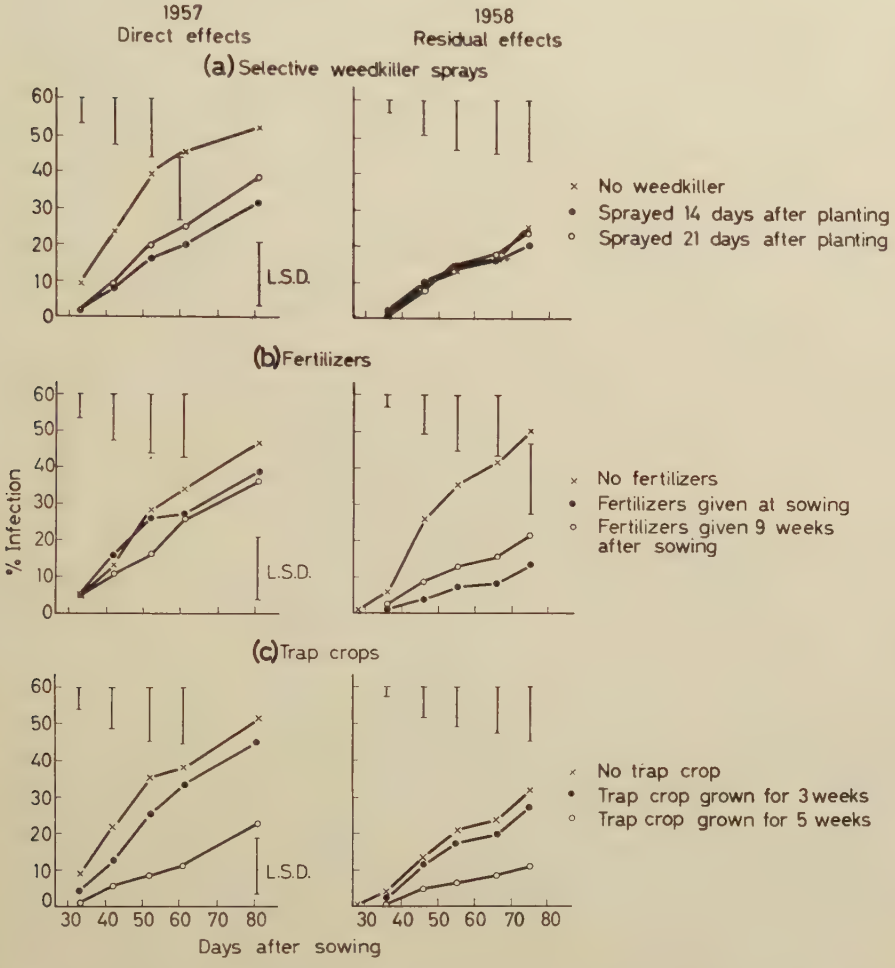

Figure 1. Direct and residual effects of weedkiller sprays, trap crops and fertilizers on the incidence of Striga hermonthica *on sorghum (measured as percentage infection)*

Although 2,4-D halved the parasitic growth in the first season and presumably decreased seed production, this had no effect on the incidence of *S. hermonthica* in the second sorghum crop.

Sorghum yields—The yields in 1957 were inversely proportional to the severity of the infestation (*Table 1*). Unsprayed, heavily parasitized, sorghum yielded 1 600 lb/acre of grain; sprayed crops gave about 2 400 lb. Although the individual spray treatments affected grain yields similarly, sprays with 1 lb of 2,4-D increased straw yields more than did sprays with 2 lb. Similarly,

spraying two weeks after planting increased yields more than spraying later. In 1958 there was no effect on the incidence of *S. hermonthica* and no effect on sorghum yields.

Table 1. Direct (1957) and residual (1958) effects of selective weedkiller (2,4–D) sprays, trap cropping with Sudan grass and fertilizers on the yields (lb/acre) of sorghum grown in land infested with Striga hermonthica

(a) Selective weedkiller sprays

Crop		No spray	Conc. of 2,4–D/acre		Sprayed, weeks after sowing	
			1 lb	2 lb	2	3
1957	Grain	1 600	2 480*	2 320*	2 420*	2 380*
	Straw	4 650	6 020*	5 150	6 010*	5 160
1958	Grain	3 000	3 040	2 960	3 090	2 910
	Straw	5 550	5 850	5 850	5 810	5 890

(b) Trap cropping

Crop		No trap crop	Sudan grass grown before sorghum for	
			3 weeks	5 weeks
1957	Grain	1 940	2 270	2 510
	Straw	5 780	6 000	4 420*
1958	Grain	2 770	2 960	3 270*
	Straw	5 640	5 760	5 970

(c) Fertilizers

Crop		No fertilizers	N and P given, weeks after sowing			
			0	3	6	9
1957	Grain	905	3 510*	3 790*	3 000*	1 440*
	Straw	3 350	7 010*	6 440*	5 490*	4 730*
1958	Grain	2 150	3 210*	3 110*	3 110*	3 420*
	Straw	4 750	5 680*	6 030*	6 180*	6 310*

* Asterisks indicate that yields of treated crops differ significantly ($p=0{\cdot}05$) from those of the respective untreated controls.

(b) *Trap crops*

Incidence of S. hermonthica—Roots of Sudan grass, the trap crop, grown for five weeks but not for three, were parasitized by numerous *S. hermonthica* seedlings. Some of the parasites emerged above ground but none flowered. In the succeeding sorghum crop parasitic aerial stems began to appear about three weeks after planting. Trap cropping for five weeks, but not for three, significantly decreased the development of *S. hermonthica* and the lower rates of infection (*Figure 1*), apparent within 30 days of planting, are reflected in the harvest weights of the parasite which decreased from 198 lb (*3·64*) to 19 lb (*2·62*) per acre. After three weeks of trap cropping 112 lb ($3{\cdot}41 \pm 0{\cdot}22$) of *S. hermonthica* developed.

Unlike the effects of 2,4-D sprays which halved the weights of *S. hermonthica*, the larger decreases caused by five weeks trap cropping were reflected in a decreased incidence of the parasite in the second sorghum crop, noticeable within 36 days of planting (*Table 2*). Seventy five days after planting, the level of infection in the second sorghum crop following five weeks trap cropping was only 10·6 per cent; where there had been no trap cropping the previous year aerial stems of *S. hermonthica* emerged from 31·5 per cent of the sorghum holes.

Table 2. Residual effects of fertilizers and trap cropping on the incidence of Striga hermonthica *(% infection) in the 1958 sorghum crop (angular transformations in italics)*

Trap crops

Days after planting sorghum	*No trap crop*	*Sudan grass grown before sorghum for*		*L.S.D. ($p = 0·05$)*
		3 weeks	*5 weeks*	
36	4·3	2·1	0·4	
	8·1	*5·2*	*1·3*	*3·68*
75	31·5	26·7	10·6	
	32·4	*29·0*	*15·9*	*11·08*

Fertilizers (mixture of N and P)

Days after planting sorghum	*No fertilizer*	*Fertilizers given, weeks after planting*				*L.S.D. ($p = 0·05$)*
		0	*3*	*6*	*9*	
36	6·1	1·1	0·4	1·8	1·9	
	10·6	*3·6*	*1·9*	*3·8*	*4·4*	*4·74*
75	49·9	13·6	12·0	18·0	21·4	
	45·6	*19·0*	*17·7*	*22·5*	*24·3*	*14·30*

Sorghum yields—In both the direct and residual phases of the experiment the lower incidence of *S. hermonthica* after trap cropping was accompanied by increased grain yields. The more effective five week period of trap cropping increased grain yields in both seasons by about 500 lb/acre. In the first year the increase in grain was offset by a significant decrease of 1 300 lb/acre of straw.

(c) *Fertilizers*

Incidence of S. hermonthica—Adding nitrogen and phosphorus did not immediately affect the numbers of sorghum holes with parasitic aerial stems, but they did produce large, although not statistically significant, differences between the weights of *S. hermonthica* per acre. Adding nitrogen and phosphorus at sowing and three weeks later decreased the weights of parasite from 77 in the unmanured to 52 and 28 lb/acre; manuring later, six and nine weeks after sowing, increased the weights to 166 and 129 lb/acre respectively.

Although without effect immediately after being applied, nitrogen and phosphorus greatly decreased the level of infection in the second sorghum crop, and the effects were independent of the original date of application.

The residual effects of fertilizers decreased infection from 6·1 per cent in the unmanured to *ca.* 1·3 per cent after 36 days, and from 49·9 to 16·2 per cent after 75 days (*Table 2*).

Sorghum yields—The effects of nitrogen and phosphorus in the first year varied with their dates of application. Giving fertilizers at sowing and three weeks later increased yields of grain from 905 to 3 650 lb/acre, and of straw from 3 350 to 6 780 lb/acre. With further delays the increases successively diminished.

In the second year, in contrast, the residual effects were independent of the date of application. The average yields of grain and straw increased from 2 150 and 4 750 in the unmanured to 3 210 and 6 060 lb/acre respectively.

DISCUSSION

Although this paper describes attempts to grow worthwhile sorghum crops on land severely infested with *S. hermonthica*, the possibilities of preventing damaging infestations should not be ignored. On irrigated crops the increase of *S. hermonthica* may be prevented, or at least its rate of increase slowed, by lengthening the intervals between successive susceptible crops (Saunders, 1933), by applying fertilizers (Last, 1960a, b) and by growing resistant varieties of sorghum (Saunders, 1942; Jenkins, 1945; Doggett, 1953 and Williams, 1959).

Trap cropping with Sudan grass for five weeks greatly decreased the incidence of *S. hermonthica* in two successive sorghum crops: spraying with selective weekdiller, in contrast, only affected the parasite in the first year. In the first crop 2,4-D sprays greatly decreased the early levels of infection but by harvest the effect was smaller and the weight of *S. hermonthica* on unsprayed sorghum was only twice that on sprayed crops (see Wilson-Jones, 1956). Trap cropping also decreased the early levels of infection but, unlike the effects of 2,4-D, these decreases persisted to harvest, when the weight of parasite was one tenth that in the controls, and through to the second sorghum crop. Presumably the decreased vegetative growth was reflected by a significantly lower level of seed production.

Although trap cropping gave longer protection than 2,4-D, the benefits gained in the first season were not proportionately larger. On the contrary the short-lived effects of 2,4-D increased grain yields by 50 per cent from 1 600 to 2 400 lb/acre, whereas effective trap cropping gave only a 30 per cent increase from 1 940 to 2 510 lb/acre of grain. These results emphasize the need to protect young sorghum plants because infection then seems most damaging (Last, 1960a). Perhaps the benefit gained by planting Sudan grass was partly offset because the grass depleted the soil of nutrients. As suggested by Timson (1945a), this loss of nutrients should be corrected before planting cash crops. In my experiment the error was high and a significant interaction between the trap crop and fertilizer treatments was not detected.

Severely infested land is usually infertile and must be given fertilizers, which themselves affect the development of *S. hermonthica*, to gain the full advantage from spraying and trap cropping. The host:parasite relation seems to vary at different levels of fertility. Fewer and smaller aerial stems of *Striga* spp. emerge on well grown than on poorly developed hosts (Solomon, 1952 and Last, 1960a, b). This difference may explain the discrep-

ancy between the direct and residual effects of fertilizers in my experiment. In the first season, when the incidence of *S. hermonthica* was not significantly affected by fertilizers, the unmanured plots yielded 905 lb/acre of grain; in the second year, when there were large residual effects, decreasing *S. hermonthica* and increasing sorghum yields, the unmanured plots yielded 2 150 lb/acre.

The choice between using a curative, e.g. trap crop, or a palliative, e.g. selective weedkiller, is mainly determined by the local farming practice (Wilson-Jones, 1953b). Trap cropping, which has been used successfully to control *Striga lutea* on maize in S. Africa (Saunders, 1933) and Rhodesia (Timson, 1945b), may be used in the Sudan to eliminate *S. hermonthica*, but compared with 2,4-D, which can be either sprayed or watered on to sorghum before aerial stems of *S. hermonthica* emerge (Kumar *et al.*, 1949; Wilson-Jones, 1952 and Tarr, 1957), it has many practical disadvantages.

SUMMARY

Sorghum crops were grown in 1958 to assess the residual effects of treatments applied in 1957 to control *Striga hermonthica*. Trap cropping with Sudan grass for five weeks, but not for three, significantly decreased the incidence of *S. hermonthica* and increased grain yields of sorghum planted in both 1957 and 1958 by 500 lb/acre; in the first season straw yields were decreased.

Spraying, two to three weeks after planting, with 0·8 to 1·6 lb/acre of the sodium salt of 2,4-dichlorophenoxyacetic acid delayed the emergence of *S. hermonthica* and increased sorghum grain and straw yields in 1957, but had no residual effect in 1958.

Giving 80 lb nitrogen and 40 lb phosphorus pentoxide per acre in 1957 increased yields of sorghum in 1957 and 1958. The increases in the first season varied with the dates of application; nitrogen and phosphorus given at sowing, and three, six and nine weeks later, increased grain yields from 905 to 3 510, 3 790, 3 000 and 1 440 lb/acre respectively. In 1958 the residual effect, an increase from 2 150 to 3 210 lb/acre of grain, was the same for all dates of application. The incidence of *S. hermonthica* was not significantly affected by fertilizers in 1957 but less developed in 1958 where nitrogen and phosphorus were given in 1957.

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The Influence of Seed Quality on the Early Growth of Cashew

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Cashew nuts are one of the major agricultural exports of Tanganyika, taking fourth place in annual value to the territory after sisal, cotton and coffee respectively. The amounts and value of the crop exported in recent years were:

Year	*Weight in tons*	*Value in £*
1957	33 651	1 514 000
1958	31 310	1 086 509
1959	33 210	1 561 000

The cashew nuts are exported to India, where they are processed, and then re-exported to North America, Great Britain and other European countries. Most of the nuts are produced in the Southern Province by African farmers on small holdings. There are a few large plantations in the Province and there are some 1 500 acres of cashew planted on the Tanganyika Agricultural Corporation farms in the Nachingwea area.

The common method of propagating cashew in Tanganyika is by seed. As cashew is a cross-pollinated plant, the progeny grown from the seed of any one tree are heterozygous. Seed grown from high yielding trees will only produce high yielding trees by chance. Budding, cuttings and grafting were tried at Nachingwea as methods of vegetative propagation, but none met with any measure of success. The air-layering method of vegetative propagation has been fairly successful at Nachingwea, and with refinements of technique could probably be greatly improved. At present however, due to scant information on the performance of individual trees, there are no known high yielding trees with other desirable characteristics from which it would be advisable to propagate air-layers on a large scale. It is unlikely that reliable records of individual trees will be available for some time, and it is therefore probable that propagation by seed will be the normal method of establishing cashew for some years to come.

A method of seed selection which ensures a good germination and the possibilities of producing more vigorous, healthy and higher yielding trees within a heterozygous population would therefore be of considerable value.

REVIEW OF LITERATURE

It has been fairly generally assumed by farmers that large well-filled seeds were more likely to germinate and give rise to healthy seedlings than small shrunken seeds. Thus seed weight, or size or density have often been quoted as measures of seed quality, although there has been some confusion between these three attributes. This assumption has often, although not

always, been supported by experimental evidence. For example, Laycock (1951) showed that tea seed of high specific gravity germinated better than seed of low specific gravity. He was unable to show any significant differences in the germination of large and small seeds; but after eighteen months growth it was found that the large seed had produced bigger seedlings than had the small seed.

Clegg (1954), working on cashew nuts, showed that a large proportion of the nuts that float in water have small or defective kernels. Nuts of greater density, which sank in water, gave a significantly higher weight of kernels after roasting. These observations and the work carried out by Laycock (1951) suggested that grading according to specific gravity might possibly be a useful method of seed selection in cashew nuts. With these points in mind, Turner (1956) divided an unselected sample of cashew nuts into five density classes:

A Density greater than 1·075
B Density 1·050–1·075
C Density 1·025–1·050
D Density 1·000–1·025
E Density less than 1·000.

Solutions of specific gravities of 1·000 (water),
1·025 (71 g of sugar made up to 1 litre with water),
1·050 (136 g sugar made up to 1 litre with water), and
1·075 (200 g sugar made up to 1 litre with water), were made. The nuts were graded into density classes by placing them in each solution for five minutes. Those that floated and those that sank were separated. After a thorough washing, the nuts were dried in the sun and each grade weighed.

A study was made of the relationship of density to germination behaviour and the output of kernels after roasting. The results may be summarized as follows:

(*1*) Nuts of greater density germinated quicker than nuts of lower density.
(*2*) Total viability was generally greater with grades of higher specific gravity.
(*3*) Very large nuts were all of relatively low density. Their viability and rate of germination was poor.
(*4*) Output of roasted kernels from grades of higher density was significantly better than from grades of lower density.
(*5*) The percentage of sound kernels progressively increased with increasing specific gravity.

The important factor from the grower's point of view, is that nuts of greater density give a higher percentage germination. The density grades A to E listed above gave germination percentages of 90, 80, 80, 65 and 35 respectively.

MATERIALS AND METHODS

The present study was undertaken to determine whether any relationship existed between seed density of cashew nuts and the characteristics of the resultant seedlings at various intervals of time after planting.

The cashew nuts used in this experiment were part of a random sample taken from unselected nuts harvested at Namanga and Ilala Farms, Nachingwea, in November 1957.

The nuts were cleaned by hand to remove pieces of adhering cashew apple, and divided into the five density classes according to the method devised by Turner (1956). The nuts were washed and dried after grading in order to prevent fungus growing on the sugary surface. The experiment described below was planted on the Experimental Farm of the Southern Regional Research Centre, Nachingwea, on 7 January 1958, this date being the first suitable time for planting cashew in this season. The climate is characterized by a single rainy season and a long dry season. The rains normally begin in late November, and continue until the end of April to mid-May. Seasonal rainfall totals (i.e. from 1 November to 29 May) vary considerably, from 20·6 to 45·4 in., with a mean of 32·7 in. After the cashew was planted, adequate rains occurred, so germination began immediately and suffered no retardation.

The experiment was laid out in a randomized block design with six replications and five treatments. The treatments represented each of the five density grades. Single row plots each containing 20 planting stakes were used for each treatment. The spacing was 3 yards between rows and 3 yards between stakes within the row. This is not the normal spacing used for cashew, but as it was not envisaged that recordings would carry on for more than two years at the most, this spacing was considered adequate for the purpose.

Allowing for the fact that the percentage germination of the five density grades was expected to differ considerably, seeds were planted at differing numbers per stake according to the expected germination of each grade. The numbers of seeds planted around each stake were 3, 4, 6, 7, and 7, for each of the density grades A to E respectively. It was expected that this would ensure at least one seedling per stake and that ideally 120 seedlings per density grade would be available for recording. This was considered a practical number to ensure reliable averages in the results. The nuts were planted at a depth of 1 in. below the surface.

On the day before initial recordings were due to take place, the seedlings were thinned out to one per stake, the most vigorous seedling being retained.

The following data were collected at various stages of the experiment:

Percentage germination

Counts of nuts germinated around each stake were made 16 days after planting and continued at weekly intervals until 44 days after planting. At this time thinning to one seedling per stake was done. The few seedlings which germinated after 20 February 1958, when first growth recordings began, were all removed.

Seedling height

The height measurements were taken from the ground level to the tip of the longest leaf at the apex of the main stem.

Leaf number

The numbers of leaves per seedling were recorded, until a date at which it became impracticable to make further counts.

Diameter of stem

Measurements were taken just below the first node (i.e. cotyledonary node) with measuring callipers.

The above recordings of seedling height, number of leaves and diameter of stem were carried out at fortnightly intervals until 27 November 1958, with a gap in the recordings of eight weeks in July and August 1958 due to the pressure of work on annual crops.

Leaf length and breadth

The first leaf measurements were taken on 11 April 1958 (i.e. 94 days after planting), when the lowest specific gravity grade had an average of 13 leaves per plant and the highest specific gravity grade had an average of 18 leaves per plant. The five largest mature leaves on each seedling were measured. Length measurements were taken from the point where the leaf lamina joined the petiole to the tip of the leaf. Breadth measurements were taken across the widest part of the leaf.

Further leaf measurements were taken in September 1959.

Percentage of trees flowering and the number of flowering panicles per tree

Counts of the number of trees flowering and the number of flower panicles per tree were taken in September 1959, at the peak of the first flowering season. The average number of panicles per tree from the various density grades was calculated from the trees bearing flowers and not from the total number of trees.

Percentage loss of stand during the trial

Plant counts were made on 27 November 1958 and 15 September 1959, and percentage losses of stand during the period from which recordings were initially started were recorded.

The whole experiment was dusted at irregular intervals with 0·5 per cent benzene hexachloride to prevent damage by *Helopeltis* spp., which attack the young shoots causing a serious die-back.

RESULTS

Percentage germination

The course of germination of the nuts from the five density grades is shown in *Figure 1*. This graph confirms Turner's results that cashew nuts of different specific gravities vary considerably both with regard to speed of germination and to total viability. In general, nuts of greater density germinated quicker than nuts of lower density, although there are wide ranges within each grade. The final germination percentages for the present trial of 50, 48, 40, 34 and 18 for the density grades A to E, are overall much lower than the percentage germination data obtained from the same grades in Turner's trial. This difference may be due to a seasonal effect on the overall quality of the nuts, but it is more probable that the difference lies in the fact that the present experiment was planted in the field and was therefore subject to the natural hazards of external conditions, whereas the experiments carried out by Turner were laid out in trays.

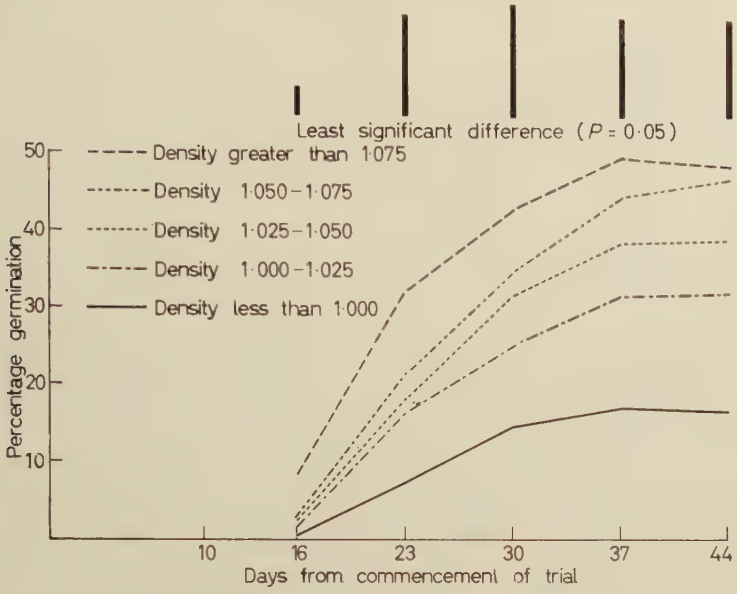

Figure 1. Germination of cashew nuts graded according to density

Due to lower germination than was expected, an ideal stand of 120 trees for each density grade within the trial was not obtained. The actual number of planting stakes having at least one seedling, from germination to the first date of growth recording, is shown in *Table 1.*

Table 1. Actual number of planting holes within the trial which contained at least one seedling, from commencement of germination to the date of initial recording

Density grade	*Date in 1958*				
	23 Jan	*30 Jan*	*6 Feb*	*13 Feb*	*20 Feb*
A	27	74	92	97	98
B	12	74	93	108	107
C	16	68	98	103	104
D	12	77	90	100	102
E	3	53	71	82	82

The number of planting holes containing at least one seedling is constantly lower in the density grade E, but there is no marked difference between the other four grades. The number of stakes with at least one seedling on 20 February 1958 represents the number of trees on which recordings were begun.

Seedling height (*see* Table 2)

The density grade E produced seedlings significantly smaller than the other grades throughout the period of recording. At the earlier dates of recording there was a gradation in height of seedlings from the low to the high density grades, but this tended to become masked in later recordings

This lessening of the difference between the various grades is not surprising for the height factor, when one considers the inherent variability within the cashew on which the experiment was carried out. The habit of the trees can vary considerably between a very tall single-stemmed tree and a small tree with many branches and a bush-type habit.

Table 2. Growth of cashew seedlings in relation to density of seed

Density grade	*20 March 1958*			*13 November 1958*		
	Mean height in.	*Mean no. of leaves*	*Mean stem diam. mm*	*Mean height in.*	*Mean no. of leaves*	*Mean stem diam. mm*
A	9·38	12·72	5·51	43·75	201·14	30·52
B	9·22	11·94	5·39	41·13	190·33	29·81
C	9·07	11·68	5·34	42·90	190·40	29·72
D	9·11	11·53	5·22	41·47	170·35	28·01
E	7·63	10·24	4·69	34·47	149·46	26·86
L.S.D.						
$P = 0{\cdot}05$	0·92	1·45	0·37	4·87	54·03	2·87
$P = 0{\cdot}01$	1·25	1·98	0·50	6·65	73·69	3·92

Leaf number (*see* Table 2)

The leaf number of the young trees is markedly different between the density grades, and the divergences between most of the grades become greater as time goes on. This character is not masked by the habit of the trees. Although it is possible that the number of leaves per tree is partly determined genetically, it is certainly influenced by the seed quality.

Diameter of stem (*see* Table 2)

The diameter of the stem of seedlings maintains a difference according to the density grade of the nuts and the differences tend to diverge throughout the period of recording.

Figures 2, *3* and *4* show the actual growth rates of three of the density grades for number of leaves, height and diameter of stem respectively. The graphs are plotted from the differences between the actual recordings at fortnightly intervals, and represent therefore the average amounts of growth put on during a fortnight previous to the date plotted on the graph. As has been mentioned, no recordings were made on 10 July, 24 July and 7 August 1958. The points on these graphs at 24 July are data produced by taking the differences between recordings at the dates when recordings left off and when recordings commenced eight weeks later, and dividing by the appropriate number to get an average. This average gives an estimate of the trends of growth.

Figure 2 shows that marked ' flush ' periods occur in leaf production in June and October and that there may be another imminent flush period sometime after the end of November when recordings ceased. The graphs for seedling height and diameter of stem show that for these factors growth is irregular. An attempt to link the changes in rates of growth with climatic conditions was not successful, and other factors presumably mask any correlations that might be expected.

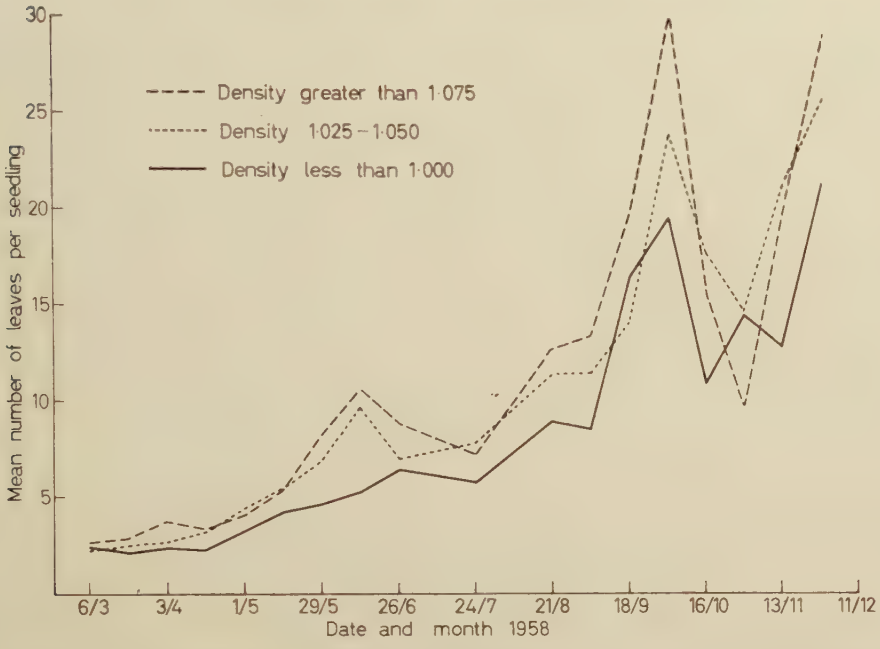

Figure 2. Growth rate of cashew seedlings graded according to the density of nuts. Mean number of leaves produced per fortnight

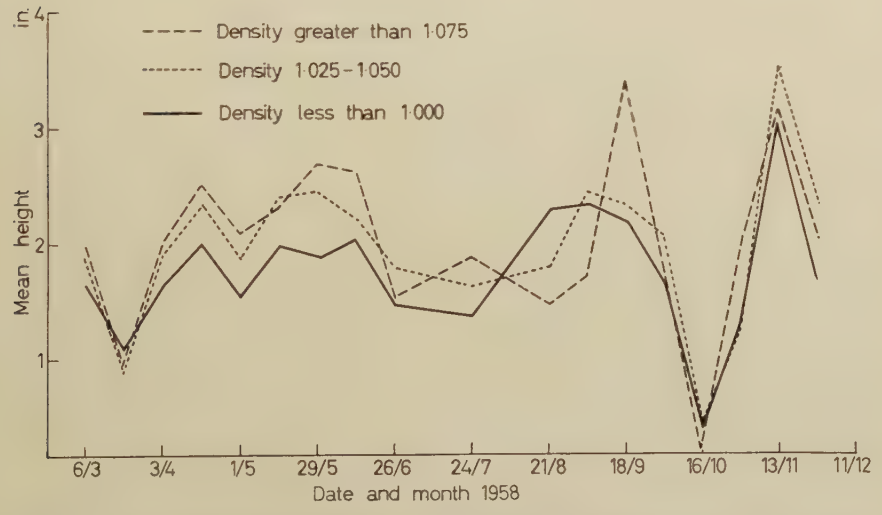

Figure 3. Growth rate of cashew seedlings graded according to the density of the nuts. Mean height increase per fortnight in inches

The important fact illustrated by *Figures 2*, *3* and *4* is that there is a marked difference between the growth rates of the high and low density grades and that the other density grade shown is intermediate.

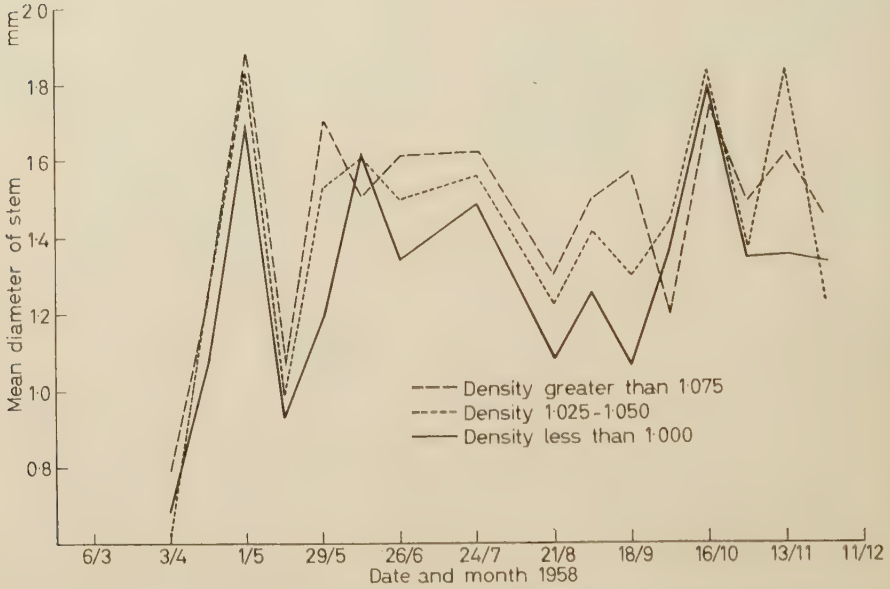

Figure 4. Growth rate of cashew seedlings graded according to the density of the nuts. Mean increase in diameter of stem per fortnight in millimetres

Leaf length and breadth

Table 3. Average length and breadth of leaves in inches from seedlings graded according to density of nuts (11 April 1958)

Density grade	*Length of leaf*	*Breadth of leaf*
A	5·13	1·77
B	5·38	1·73
C	5·34	1·71
D	5·17	1·68
E	4·65	1·54
L.S.D. $P = 0{\cdot}05$	0·68	0·78

On 11 April 1958 the recordings of leaf width and length show gradations from the low to high density grades.

Similar measurements taken in September 1959 showed no difference at all between the density grades. It is presumed that by this time, any inherent variability between trees in leaf shape and size had masked any differences that there might have been; or that a sample of five leaves from each tree was insufficient to show any small differences on trees of this size.

Percentage of trees flowering and number of panicles per tree

There is a marked difference between density grades in percentage of flowering trees at the peak period of flowering in the first flowering season (i.e. September 1959). The differences between grades in the number of flowering panicles per tree are not significant and not very great. There

Table 4. Flowering characteristics of cashew trees graded according to the density of the nut, in September 1959

Density grade	*Percentage of trees flowering*	*Average number of flowering panicles per tree*
A	73	13·4
B	71	13·9
C	69	13·4
D	57	11·2
E	60	11·4
L.S.D. $P = 0{\cdot}05$		2·9

does seem to be some difference between the two low density grades and the three high density grades, however. Considering the heterogeneous nature of the crop, it is remarkable that any differences whatever are showing at this stage.

Percentage loss of stand during the experiment

Table 5. Percentage loss of stand during the period of the experiment, of cashew seedlings graded according to density of nuts

Density grade	*Percentage loss on 27 Nov 1958*	*Percentage loss on 15 Sep 1959*
A	5	8
B	5	11
C	1	2
D	10	13
E	11	18

There is a greater loss of stand in low density grades than high density grades. This loss of stand is presumably due to inherent weakness in the plants.

DISCUSSION

It appears, then, that if cashew nuts of high density grades are planted, a better germination of seeds is obtained and the resultant seedlings are on the whole more vigorous, having thicker stems, more leaves and being taller than seedlings grown from nuts of a low density grade. Furthermore the percentage loss of stand is lower from high specific gravity grades than from low specific gravity grades. There are also indications that these vigorous seedlings produced from high density nuts will produce higher yielding trees. It seems reasonable to infer also, that the more vigorous growth exhibited above ground, by seedlings grown from high quality nuts, will also be shown below ground in the root system.

Recent research in Trinidad by Jones and Maliphant (1958) has shown that early girth measurements of cocoa trees are closely reflected by later tree performance. There is a positive correlation between the girth of the tree and the yield. It is suggested that this might apply generally to tree crops and that early girth measurements are a valuable method of hastening the study of perennials. It appears from the results presented in this paper that this hypothesis might well apply to cashew.

The reasons for the differences between these arbitrary density grades of cashew nuts cannot at present be adequately explained. The nuts of high density are ones with large kernels and so presumably have larger reserves. Probably the advantage of a large food reserve in the seed is such that it gives the seedlings a better initial start in growth which persists throughout the life of the tree. It is probable that the larger the seed, the larger will be the cotyledonary area. If so, there will be a larger initial photosynthetic area exposed, and presumably therefore a quicker build-up of dry matter, which will have an accumulative effect on future growth. The fact that nuts of a high specific gravity germinate quicker than nuts of low specific gravity might also give a better initial start, and it is possible that a factor similar to the ' time of planting effect ' in annual crops occurs. On the other hand it seems rather improbable that the difference of say a fortnight in germination could materially affect the percentage of trees flowering in the first flowering season, 20 months after planting.

Whatever the causes of the differences, whether they be physical or physiological, the results of these experiments give a practical method through which the farmer, by planting cashew nuts of a high density grade can obtain a plantation which is over all more vigorous and which it is highly probable will give higher yields.

In the past many gaps in cashew plantations have occurred after planting unselected seed, but with the planting of nuts from high density grades, ideal stands in plantations can now be obtained. All recent plantings of cashew on the Tanganyika Agricultural Corporation farms at Nachingwea have been made with nuts from high density grades, and the resultant stands and yields have been highly satisfactory.

SUMMARY

A sample of unselected cashew nuts was separated into five density grades using sugar solutions of differing specific gravities. A study was made of the relationship of density to germination behaviour and the characteristics of the resultant seedlings at various intervals of time after planting.

It was found that cashew nuts of a high density grade gave a better germination of seeds, and the resultant seedlings were more vigorous, having thicker stems, more leaves and being taller, than seedlings grown from nuts of a low density grade.

Recordings of number of trees flowering and percentages of flowering panicles per tree in the first season of flowering, indicated that the trees grown from nuts of high density would be heavier yielding than trees grown from nuts of low density.

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The Chemical Defoliation and Desiccation of Tropical Woody Plants

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Chemical defoliants and desiccants are now widely used in agriculture to facilitate the process of harvest. Chemical defoliation of young nursery plants has also proved helpful in preventing leaf infections during periods of storage. According to Osborne (1958), chemical defoliants have been used on trees in tsetse-fly infested areas of Africa; by defoliating these trees it was possible to render the conditions unsuitable for the fly to breed.

Although most commonly available defoliants are effective under certain conditions, none, according to Tukey (1954), are effective under all conditions, nor are all plants equally susceptible to chemical defoliation (Osborne, 1958; Tukey, 1954).

The present study was conducted in order to evaluate the defoliating and desiccating ability of 51 different formulations, containing 30 presumably active ingredients, when applied to 25 woody plant species of pan-tropic distribution. In addition, experiments were carried out to determine the most effective method of application of defoliants and desiccants to tropical trees as well as the effect of certain climatic conditions at the time of application.

EVALUATION OF DEFOLIANTS AND DESICCANTS

Materials and methods

In order to evaluate the effectiveness of various spray formulations on tropical woody plants, a number of locally available species, all from different genera, were selected for tests. Most of the trees and shrubs were

Table 1. List of plants used for evaluating defoliants and desiccants at Mayaguez and Guánica, P.R.

At Mayaguez	
Casearia *sp.*	Laugeria resinosa *Vahl.*
Chrysobalanos icaco *L.*	Mangifera indica *L.*
Cinnamomum cassia *Blume*	Miconia laevigata (*L.*) *DC.*
Clusia rosea *Jacq.*	Piper aduncum *L.*
Coffea robusta *L.*	Psidium guajava *L.*
Eugenia jambos (*L.*) *Millsp.*	Spathodea campanulata *Beauv.*
Ficus *sp.*	Swietenia mahogoni *Jacq.*
Inga laurina (*Sw.*) *Willd.*	Tabebuia pallida *Miers.*
At Guánica	
Bucida buceras *L.*	Krugiodendron ferreum (*Vahl.*) *Urban*
Coccolobis uvifera (*L.*) *Jacq.*	Neltuma juliflora (*Dc*) *Raf.*
Conocarpus erecta *L.*	Pictetia aculeata (*Vahl.*) *Urban*
Elaphrium simaruba (*L.*) *Rose*	Torrubia fragrans (*Dunn-Cours*) *Standley*
Guaiacum officinale *L.*	

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Table 2. Composition of fifty one different spray formulations applied to tropical woody plants

Formulation No.	Trade name or Code No.	Source	Active ingredients	Concentration %	Carrier
1			2,4,5–T butyl ester	50	Ethylene glycol mono-ethyl ester
2		Monsanto	2,4,5–T, butoxy ethoxy propanol ester	50	Ethylene glycol mono-ethyl ester
3	Kuron Brush Killer	Dow	64·5% 2–(2,4,5–T) propionic acid, propylene glycol butyl ether esters	100	None
4	Kuron Brush Killer	Dow	64·5% 2–(2,4,5–T) propionic acid, propylene glycol butyl ether esters	1	Water
5		Monsanto	2,4–D butoxy ethoxy propanol ester	50	Ethylene glycol mono-ethyl ester
6	Esteron	Dow	2,4–D, isopropyl ester	100	None
7	YF Tree and Brush Killer	Aguirre Sugar Co., P.R.	85·3% aromatic petroleum distillates, 12·2% isopropyl ester of trichloroacetic acid, 2·5% isopropyl ester of 2,4,5–T	100	None
8		Monsanto	Pentachlorophenol 83% technical grade	33	Ethylene glycol mono-ethyl ester
9	6–Ca–4	Aguirre Sugar Co., P.R.	Pentachlorophenol and aromatic distillates	50	Water
10	6–Ca–4	Aguirre Sugar Co., P.R.	Pentachlorophenol and aromatic distillates	25	Water
11	6–Ca–4	Aguirre Sugar Co., P.R.	Pentachlorophenol and aromatic distillates	10	Water
12	Golden Harvest Defoliant	Chapman Chemical Co.	Pentachlorophenol, 4 lb/gal	3	Mineral Seal Oil
13	M–562	Dow	Pentachlorophenol, 4 lb/gal	3	Mineral Seal Oil
14	Ammate	Dupont	30% Ammonium sulphamate	33	Water
15	Weedazol	American Chemical Paint Co.	50% 3–amino–1,2,4–triazole	33	Water
16	Endothal	Pennsalt	6·3% disodium endoxohexahydrophthalate	100	None
17	Endothal	Pennsalt	6·3% disodium endoxohexahydrophthalate	20	Water
18	NP 1098	Pennsalt	Butyne 1,4–diol	35	Water
19	Aero Cyanate	American Cyanamid	Potassium cyanate	28	Water
20	Shed-A-Leaf	Chipman Chemical	Sodium chlorates and borates	[2 lb/gal]	Water
21	Shed-A-Leaf	Chipman Chemical	Sodium chlorates and borates	[1 lb/gal]	Water
22	Shed-A-Leaf	Chipman Chemical	Sodium chlorates and borates	[½ lb/gal]	Water
23	ACP M–118	American Chemical Paint Co.	Dimethylamine salt of 4–(2,4–D) butyric acid	100	None
24	Lion oil	Monsanto	Aromatic petroleum oils	100	None
25	B 1613	Chemagro Corp.	Unknown	100	None
26	B 1613	Chemagro Corp.	Unknown	10	Water
27	B 1638	Chemagro Corp.	Unknown	100	None
28	B 1638	Chemagro Corp.	Unknown	10	Water
29	B 1676	Chemagro Corp.	Unknown	100	None
30	VC 186	Virginia Carolina Chem. Corp.	Tripropyl phosphorotrithioite	10	Water

Formulation No.	Trade name or Code No.	Source	Active ingredients	Concentration %	Carrier
31	VC 3–105	Virginia Carolina Chem. Corp.	Dibutyl butylphosphonate	10	Water
32	VC 1–21	Virginia Carolina Chem. Corp.	Tetrabutyl trimethylene diphosphonate	10	Water
33	VC 1–443	Virginia Carolina Chem. Corp.	Tributyl phosphorotrithioite	10	Water
34	VC 3–173	Virginia Carolina Chem. Corp.	Tributyl 2,4–dichlorobenzylphosphonium chloride	10	Water
35	TBP	Amend Drug & Chemical	Tributyl phosphate, technical grade	100	None
36	713	Phillips Chem. Co.	25% diethylxanthogen trisulphide and 75% petroleum hydrocarbon solvent	100	None
37	SD 1369		P–P *dibutyl* N–N *diisopropyl phosphinic amide*	40	Water
38	SD 1369		P–P–*dibutyl* N–N–*diisopropyl phosphinic amide*	8	Water
39			$MgClO_3$	25	Water
40	F–1	Multiple	*Weedazol* *Endothal*	*50 g Weedazol* *100 ml Endothal* *100 ml water*	Water
41	F–2	Multiple	*F–1* *Esteron* *Ammate* *Endothal*	*50 ml F–1* *50 ml Esteron* *25 g Ammate* *50 ml Endothal* *50 ml water*	Water
42	F–3	Multiple	*6–Ca–4 and Shed-A-Leaf*	*5% 6–Ca–4* *½ lb/gal* *Shed-A-Leaf*	Water
43	F–4	Multiple	*6–Ca–4 and Ammate*	*2 ml of 6–Ca–4* *100 g of Ammate* *in 100 ml water*	Water
44	F–5	Multiple	*Shed-A-Leaf and Ammate*	*20 g Shed-A-Leaf* *50 g Ammate in* *150 ml water*	Water
45	F–6	Multiple	*Lion oil and 6–Ca–4*	*10 ml 6–Ca–4 in* *190 ml Lion oil*	None
46	F–7	Multiple	*VC 1–443 and Ammate*	*5 ml VC 1–443* *25 g Ammate in* *50 ml water*	Water
47	F–8	Multiple	*VC 1–443 and NP 1098*	*5% VC 1–443* *50% NP 1098*	Water
48	F–9	Multiple	*VC 1–443 and NP 1098*	*5% VC 1–443* *50% NP 1098*	*Ethylene glycol monoethyl ester*
49	F–10	Multiple	*VC 1–443 and NP 1098*	*2·5% VC 1–443* *50% NP 1098*	*Ethylene glycol monoethyl ester*
50	F–11	Multiple	*VC 1–443 and NP 1098 and Shed-A-Leaf*	*4% VC 1–443* *38% NP 1098* *58% Shed-A-Leaf*	None
51	F–12	Multiple	*VC 1–443 and NP 1098 and B 1676*	*2% VC 1–443* *20% NP 1098* *20% B 1676*	*Ethylene glycol monoethyl ester*

mesophytes, growing characteristically in the immediate vicinity of the Federal Experiment Station at Mayaguez, on the west coast of Puerto Rico (annual rainfall approximately 80 in.). Others were xerophytic in habit and were available to us in one of the very dry regions on the south coast of Puerto Rico near the town of Guánica (annual rainfall approximately 20 in.). *Table 1* lists the 16 species used at Mayaguez and the nine species used at Guánica.

Some of the spray formulations used consisted of commercial defoliants and were applied according to the manufacturer's recommendations or diluted to various degrees with water, ethylene glycol monoethyl ester, or mineral seal oil. Other spray formulations contained experimental defoliants supplied by a number of chemical companies. *Table 2* lists the 51 different formulations used and gives other pertinent information concerning active ingredients, concentrations and carriers. It should be noted that the last 12 formulations listed were mixtures of some of the defoliants listed earlier in the same table.

The technique used in applying the formulations differed somewhat during the two years of the experiment. For the first year and a half, sprays were applied to the upper leaf surfaces only; during the last six months they were applied to both the upper and lower leaf surfaces. The reason for this change in procedure was that certain observations, to be described later in this report, indicated a much greater effectiveness of the chemicals when applied to the lower leaf surfaces than to the upper.

In the early work the chemicals were applied from a small, battery-operated microsprayer. Later, the pressure tank from a knapsack sprayer was used in conjunction with the spray head from a De Vilbiss atomizer.

Irrespective of the leaf surface sprayed or the type of sprayer used, the solutions were always applied until just before the point of run-off to all of the leaves on duplicate small branches of the plant in question. The exact amount of solution applied in each case was not recorded but usually amounted to between one and three millilitres, depending upon the number and size of the leaves.

After the solutions were applied, periodic observations were made of the effects of the treatment. In the early work such observations were made after 1, 2, 4 and 8 weeks, but later, as more effective formulations were found, observations were made after 1, 3, 7 and 14 days. The effectiveness of the treatment was expressed as the estimated percentage defoliation or desiccation.

Results

Defoliation—Of the 51 formulations tested, it was found that 37 acted primarily as defoliants and 13 acted primarily by causing desiccation or discoloration of the leaves to which they were applied. One of the formulations (No. 28) showed no activity at all. This division of activities into defoliants and desiccants was necessarily somewhat arbitrary, since in most cases the response was neither purely desiccation nor purely defoliation but rather a mixture of the two responses. By computing average percentage defoliation, or desiccation and discoloration, on the 16 species used at

Mayaguez at different times after application, it was possible to arrange the various formulations in an approximate order of decreasing activity.

In this manner, it was found that the eight top-ranking defoliants, in approximate order of decreasing activity, were Nos. 47, 48, 49, 50, 29, 33, 27 and 18. *Figure 1* is a graphical illustration of the average percentage defoliation caused by these eight best defoliants when applied to the 16 species at Mayaguez, at various times after application. It is clear that formulations Nos. 47, 48, 49 and 50 are distinctly more effective than the other four formulations. These four best formulations all contain a mixture of tributyl-phosphorotrithioite, which is the sole active ingredient in formulation No. 33, and butyne 1,4-diol, which is the sole active ingredient in formulation No. 18. It is interesting to note that all four of the combinations are more effective than either of the components by themselves.

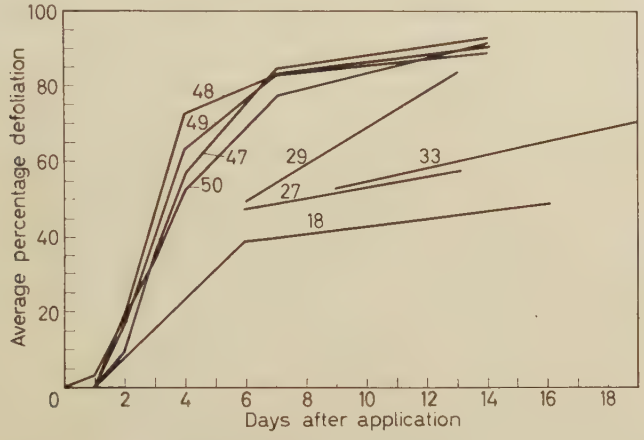

Figure 1. Average percentage defoliation at various times after application of formulations Nos. 47, 48, 49, 50, 29, 33, 27 and 18 to sixteen different species of tropical woody plants

It should be pointed out in this connection that, of the eight defoliants referred to in *Figure 1*, all except formulation No. 18 were applied to both the upper and lower leaf surfaces. Formulation No. 18, on the other hand, was applied to the upper leaf surfaces only, and for this reason, its curve is not quite comparable to the others.

At Guánica, nine of the fifty two formulations were applied to nine species. When comparing the performance of those formulations which were applied both at Guánica and Mayaguez, it appeared that defoliation was somewhat more easily obtained under the dry conditions at Guánica. *Table 3* gives the average per cent defoliation caused by these formulations when applied to the 16 species used at Mayaguez and to the nine species used at Guánica.

Large differences were observed in the sensitivity of the different plants to the various formulations. Some plants such as *Miconia laevigata* (L.) DC. and *Piper aduncum* L. were consistently easy to defoliate; 26 of the 51 formulations caused more than 50 per cent defoliation within one week on *Piper*. Other species were consistently difficult to defoliate such as *Clusia*

rosea Jacq. and *Chrysobalanos icaco* L.; not a single one of the 51 formulations caused as much as 50 per cent defoliation in *Chrysobalanos* in one week.

Desiccation—As mentioned above, 13 of the 51 formulations acted primarily by desiccating or discolouring the foliage to which they were applied.

The techniques of application and the plants treated were the same as those used for the defoliants. In fact, before a given formulation was applied, it was not known if it would act primarily as a defoliant or as a desiccant.

The observations made and recorded consisted of a visual estimation of the percentage desiccation or discoloration or spotting. If the branch in question became partially defoliated by the treatment, the desiccation or discoloration results referred to the remaining leaves on the branch.

In the great majority of cases, the desiccation observed was not a complete dehydration of the tissues, but simply a loss of turgor which gave the leaf a wilted appearance. Seldom did the leaves become crisp and dry. In many cases, the desiccation or discoloration symptoms preceded defoliation.

Table 3. Average defoliation one week after application of nine formulations to the 16 species used at Mayaguez and to the nine species used at Guánica

Formulation No.	*Average defoliation at Mayaguez per cent*	*Average defoliation at Guánica per cent*
3	5·4	24·4
10	10·1	38·1
11	31·3	45·6
14	40·3	47·5
16	20·6	41·2
21	28·8	63·1
25	20·3	58·7
33	57·7	54·4
44	47·5	47·5

The four formulations which had the most pronounced desiccating and discolouring effects were formulations Nos. 35, 12, 13 and 37. Of these, No. 35 (pure tributyl phosphate) was by far the most effective. One week after application, tributyl phosphate caused 100 per cent desiccation or discoloration in 14 of the 16 trees tested at Mayaguez. Of the remaining two species, one showed 90 per cent, and the other a trace of desiccation. In spite of this very severe desiccating effect of tributyl phosphate, the material caused only very slight, or very slow defoliation of the treated branches.

The other three formulations mentioned as having pronounced desiccating or discolouring effects were nearly equally effective, but much less so than tributyl phosphate. The response to these other three formulations further differed from that of tributyl phosphate by being a mixed defoliation and desiccation response.

EXPERIMENTS ON THE METHOD OF APPLICATION AND RELATED PROBLEMS

In addition to the above work on evaluating the effectiveness of defoliants and desiccants, three experiments were conducted to determine the relative merits of applications of chemicals to upper and lower surfaces of leaves and also to determine the effect of rain falling on the leaves shortly after the application of defoliants and desiccants.

Mode of entrance—In the first of these experiments, the objective was to compare the rate of action of two foliar desiccants when applied to the upper and lower surfaces of leaves. Six species of woody plants, all growing in the Mayaguez region were used: *Mangifera indica* L., *Swietenia mahogoni* Jacq., *Psidium guajava*, *Ficus* sp., *Eugenia jambos* (L.) Millsp., and *Clusia rosea* Jacq. Microscopic examination of the leaves of these plants revealed that none of them had any stomata on the upper surfaces, whereas on the lower surfaces they had 54 734, 60 526, 94 737, 34 210 and 7 342 stomata per square centimetre respectively*.

Two desiccants were applied, each at two concentrations: 10 per cent and 100 per cent TBP (tributyl phosphate) and full strength and half strength 6–Ca–4 (pentachlorophenol and aromatic distillates). Each concentration of both desiccants was applied separately with a microsprayer to the upper and lower leaf surfaces of all of the leaves on two different branches of each of the six species. The amount of spray applied varied according to the number and size of the leaves, which were covered to a point just before run-off. Following each application, a record was made of the per cent injury and type of response obtained at 2, 5, 10, 30 and 60 minutes after application, as well as after 7 and 24 hours, and 5, 6, 7 and 8 days.

Table 4 shows the amount of desiccation or discoloration observed 1 and 24 hours after application of the two concentrations of TBP to the upper and lower leaf surfaces of the six trees tested.

It was further noted that all of the 12 TBP treatments to the lower leaf surfaces caused some injury within two minutes; whereas of the 12 TBP treatments to the upper leaf surfaces, 10 caused no injury within five minutes.

Table 5 shows the amounts of desiccation and discoloration observed 1 and 24 hours after application of the two concentrations of 6–Ca–4 to the upper and lower leaf surfaces of the six trees tested. Further it was noted that two minutes after application, seven of the 12 lower-surface 6–Ca–4 treatments caused some injury; whereas of the 12 upper-surface treatments, 10 showed no injury within five minutes.

A second experiment was performed to determine which of the following three methods of applying defoliants was most effective: upper-surface application, lower-surface application, or application to both leaf surfaces. Two defoliants were used: NP 1098 (a 35 per cent aqueous solution of butyne 1,4-diol) and Shed-A-Leaf (sodium chlorates and borates, 1 lb/gal of water). These formulations were applied with the microsprayer to the appropriate leaf surfaces at a time when the stomata were open (10 to 11 a.m. during July). Duplicate small branches of the trees listed below were treated to a point just before run-off: *Mammea americana* L., *Mangifera indica* L., *Clusia rosea* Jacq., *Casearia* sp., *Eugenia jambos* (L) Millsp. Microscopic examination of the leaves of these plants revealed that none of them had any stomata on the upper surfaces, whereas on the lower surfaces they had 37 342, 54 734, 7 342, 23 158 and 21 059 stomata per square centimetre respectively*.

At periods of 2, 5, 7 and 14 days after spraying, observations were made

* The indicated stomatal frequencies are based upon five countings randomly distributed over the leaf surface in question.

Table 4. Amount of desiccation observed 1 and 24 hours after application of two concentrations of TBP to the upper and lower leaf surfaces of six tropical trees

Genus	Desiccation after 1 hour				Desiccation after 24 hours			
	100% TBP Leaf surface		10% TBP Leaf surface		100% TBP Leaf surface		10% TBP Leaf surface	
	Upper per cent	Lower per cent	Upper per cent	Lower per cent	Upper per cent	Lower per cent	Upper per cent	Lower per cent
Swietenia	60	15	15	20	95	100	25	75
Mangifera	*Trace*	30	0	20	75	70	5	70
Eugenia	0	80	*Trace*	50	100	100	5	75
Psidium	100	100	20	90	100	100	35	100
Ficus	30	75	0	75	85	90	15	60
Clusia	0	10	0	30	1	75	1	50

Table 5. Amount of desiccation observed 1 and 24 hours after application of two concentrations of 6-Ca-4 to the upper and lower leaf surfaces of six tropical trees

Genus	Desiccation after 1 hour				Desiccation after 24 hours			
	Full-strength 6 Ca–4 Leaf surface		Half-strength 6–Ca–4 Leaf surface		Full-strength 6–Ca–4 Leaf surface		Half-strength 6–Ca 4 Leaf surface	
	Upper per cent	Lower per cent	Upper per cent	Lower per cent	Upper per cent	Lower per cent	Upper per cent	Lower per cent
Swietenia	*Trace*	35	*Trace*	30	75	100	85	95
Mangifera	*Trace*	25	*Trace*	30	40	100	10	95
Eugenia	0	*Trace*	0	0	0	95	*Trace*	70
Psidium	*Trace*	60	*Trace*	50	15	100	25	100
Ficus	0	50	0	20	15	85	15	50
Clusia	0	*Trace*	0	0	*Trace*	75	50	30

*Table 6. Defoliation responses of five tropical trees to NP 1098 and Shed-A-Leaf to the upper, lower, and both leaf surfaces**

Genus	*Leaf surface*	*Defoliation observed*							
		Days after treatment with NP 1098				*Days after treatment with Shed–A–Leaf*			
		2 per cent	*5 per cent*	*7 per cent*	*14 per cent*	*2 per cent*	*5 per cent*	*7 per cent*	*14 per cent*
Clusia	*Upper*	0	0	0	0	0	0	0	0
	Lower	0	0	0	100	0	0	0	50
	Both	0	0	0	50	0	0	0	0
Mangifera	*Upper*	0	27	55	55	0	0	10	10
	Lower	0	32	63	100	0	6	35	90
	Both	0	50	67	100	0	0	65	95
Mammea	*Upper*	0	0	0	0	0	0	5	10
	Lower	0	0	31	70	0	15	22	30
	Both	0	0	36	65	0	5	12	30
Eugenia	*Upper*	0	0	17	17	0	0	10	10
	Lower	0	100	100	100	0	0	17	37
	Both	0	97	100	100	0	35	52	70
Casearia	*Upper*	0	0	0	17	0	0	0	5
	Lower	0	0	21	40	0	0	35	35
	Both	0	7	15	55	0	0	45	45

*The responses in this table are average values of duplicate observations.

of the percentage defoliation in each treatment. The results are given in *Table 6*. It can be seen that upper-surface applications always resulted in less defoliation than did applications involving the lower surfaces.

Effect of rainfall—A third experiment was performed to determine the effect of rain falling five and 30 minutes after the application of two different desiccants and two different defoliants to the foliage of *Ficus* sp., and *Swietenia mahogoni* Jacq.

Table 7. Desiccation responses of Ficus *to TBP followed by rain five and 30 minutes after application*

Time after application	*Desiccation effect of TBP followed by*		
	no rain per cent	*rain after 5 min per cent*	*rain after 30 min per cent*
5 min	5	10	—
10 min	10	15	—
30 min	15	15	20
1 h	25	25	25
1·5 h	30	25	27
3 day	95	98	98
5 day	95	98	98
12 day	100	100	100

Table 8. Defoliation in Ficus *caused by VC 1–443 and NP 1098 followed by rain five and 30 minutes after application*

Time after treatment days	*Defoliation effect of 10% VC 1–443 with*			*Defoliation effect of NP 1098 with*		
	no rain per cent	*rain after 5 min per cent*	*rain after 30 min per cent*	*no rain per cent*	*rain after 5 min per cent*	*rain after 30 min per cent*
3	0	0	0	7	0	0
5	100	0	5	100	2	10
12	100	90	20	100	80	90
18	100	90	60	100	80	90

Table 9. Defoliation in Swietenia *caused by VC 1–443 and NP 1098 followed by rain five and 30 minutes after application*

Time after treatment days	*Defoliation effect of 10% VC 1–443 with*			*Defoliation effect of NP 1098 with*		
	no rain per cent	*rain after 5 min per cent*	*rain after 30 min per cent*	*no rain per cent*	*rain after 5 min per cent*	*rain after 30 min per cent*
3	0	0	0	0	0	0
5	35	0	0	40	80	85
12	100	80	95	100	100	100
18	100	100	100	100	100	100

The desiccants used were half-strength 6–Ca–4 (pentachlorophenol and aromatic distillates) and TBP (tributyl phosphate). The defoliants were 10 per cent VC 1–443 (tributyl phosphorotrithioite) and NP 1098 (35 per cent aqueous solution of butyne 1,4–diol). These chemicals were applied by microsprayer to both leaf surfaces of all of the leaves on small branches of the trees in question.

Artificial rain, in the form of a vigorous water spray from a knapsack sprayer, was applied five and 30 minutes after application of the chemicals. The controls consisted of sprayed branches without rain. Observations of the effects of the treatments were made at periodic intervals after the application of the chemicals.

It was found that the artificial rain made no difference to the effectiveness of either of the two desiccants on either of the two plant species. *Table 7*, which shows the results obtained with TBP on *Ficus*, illustrates this point.

The results obtained with the two defoliants on the two species are listed in *Tables 8* and *9*.

On *Ficus*, the effect of rain, falling shortly after the application of the spray, appears to be a delaying of the initial onset of defoliation as well as a reduction in the final amount. On *Swietenia*, however, this effect of rain was not very pronounced, if present at all.

DISCUSSION

Wide variations were observed in the relative effectiveness of 51 formulations of 30 defoliating and desiccating agents. Likewise, wide variations were observed in the susceptibility of the plant species tested. These observations agree with those of OSBORNE (1958) who noted variation in the susceptibility to defoliating agents among tropical plants, and with those of BROWN and RHYNE (1954) who found inherent differences among different species and varieties of cotton.

OSBORNE (1958) has observed that the most effective defoliants in mixed stands of tropical vegetation are not to be found among the conventional growth-regulator type compounds. The present study agrees with this observation in as much as such a conventional type growth-regulator as 2,4,5–trichlorophenoxyacetic acid, butyl ester (formulation No. 1) gave no defoliation at all on the 16 species tested at Mayaguez two weeks after application. Formulations containing butyne 1,4-diol and tributyl phosphorotrithioite, on the other hand, gave, within one week, an average defoliation on the 16 species as high as 80 to 85 per cent.

OSBORNE (1958) postulated that the defoliation which she obtained with 2,4,5-T was due to premature senescence of the leaves causing the production of an abscission-accelerating factor. The time required for this defoliation to occur was between two and four weeks. In the present case, considerable defoliation was obtained as early as two days after application of those formulations containing butyne 1,4-diol and tributyl phosphorotrithioite. It would seem that the underlying mechanism of action in these cases must be different from that operating with the growth-regulator type compounds.

The apparent difference in the ease with which defoliation was accomplished in the Guánica and Mayaguez areas may have been due to several factors. The species used in the two areas were not the same, so that the ease of chemical defoliation may have been a characteristic of the species. The environment in the two areas is markedly different. At Guánica, the annual rainfall is about 60 in. less than at Mayaguez.

Concerning the experiments involving application of defoliants and desiccants to different leaf surfaces, there seems to be no doubt that the materials tested entered the leaf tissues primarily through the surfaces with

stomata. This finding may become an important consideration in any field applications of the materials tested here.

The difference between the effects of simulated rain on defoliants and desiccants is undoubtedly a reflection of the difference in speed with which the two groups of formulations acted. Throughout this study it was repeatedly found that the symptoms of desiccation and discoloration showed up much sooner (sometimes within two to three minutes after application) than did the defoliation response (the quickest defoliation response was with formulation No. 48 on *Coffea*, which gave 60 per cent defoliation in 24 hours). The fact that simulated rain, shortly after application, reduced the effectiveness of defoliants more than that of desiccants seems to indicate that part of the difference in speed with which the two act, is caused by a difference in the rate of entry of the two types of compounds into the leaf.

SUMMARY

Fifty one different formulations were tested for their defoliation or desiccation and discoloration effects on 25 species of tropical woody plants. Thirty seven of the formulations acted primarily as defoliants and 13 acted primarily by causing desiccation or discoloration of the leaves to which they were applied.

The most effective defoliant formulations were those containing butyne 1,4-diol, tributyl phosphorotrithioite or mixtures of these two compounds. Mixtures were found to be more effective than either of the components by themselves. One formulation, containing a mixture of these two active ingredients, gave an average of 82 per cent defoliation one week after application on the 16 trees tested in the Mayaguez area.

Although not all formulations were tested in both areas, defoliation appeared to be more easily attained in the very dry region on the south coast of Puerto Rico than in the mesophytic area around Mayaguez.

Of the 13 formulations showing desiccating activity, tributyl phosphate clearly stood out as the most effective. Within one week after its application, tributyl phosphate caused 100 per cent desiccation or discoloration of the leaves of 14 of the 16 trees tested.

Experimental evidence was obtained showing that the primary path of entry of both defoliating and desiccating formulations was through the stomatal openings.

The effect of a brief shower falling shortly after the application of defoliants and desiccants was determined. It was found that rain falling five minutes after the application of tributyl phosphate did not reduce its effectiveness as a foliar desiccant. Rain falling five and 30 minutes after the application of two different defoliant formulations reduced their effectiveness on one of the two species tested.

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The Effect of Spacing on the Yield of Egg Plant (Solanum melongena)

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The egg plant is cultivated in Trinidad and throughout the tropics and sub-tropics for its fruits, which are used as a vegetable. As grown locally, the plants are generally spaced 3 ft to 4 ft apart. Experience with many other crops—cereals (Hudson, 1941), potatoes (Boyd and Lessels, 1954), dwarf beans (Campbell and Hodnett, 1960), groundnuts (Walker, 1958), rice (Rosher, 1959), tomatoes (Paul, 1934)—has shown that considerably higher yields can be obtained by closer planting or higher seed rates than those commonly used. In the absence of any published experimental data on the spacing of the egg plant, experiments were carried out at the College in the years 1956–1958 inclusive to investigate the effect of reducing the spacing between the plants. This note puts on record the results of these experiments.

The Experiments

In 1956, six planting distances were tested ranging from 4 ft square by 6 in. intervals to 1 ft 6 in. square. There were four replicates. In the subsequent years, four spacings were tested, the two widest spacings being omitted and fertilizers—nitrogen (N), phosphorus (P), potassium (K)—were introduced as additional factors, each at two levels. Sulphate of ammonia (21 per cent nitrogen), superphosphate (48 per cent phosphorus pentoxide) and muriate of potash (58 per cent potassium oxide) were each applied at rates of 1 and 2 cwt/acre in 1957; in 1958 the lower level was zero. The 4×2^3 designs were arranged in randomized blocks of 8 plots, by means of confounding. After using square plots consisting of 49 plants gross (25 plants net) in the first two years, an approximately constant plot size of $17\frac{1}{2}$ ft square was used in the third year. The standard errors per plot in these experiments were 27·7, 30·2 and 16·6 per cent respectively.

The crops were grown on the College farm on light sandy-silty soils. They were planted from the nursery on to cambered beds 24 ft wide towards the end of the wet season (November–December). Weeding and moulding of the plants in the field was carried out as necessary and irrigation water was applied through an overhead irrigation system at a rate equivalent to 1 in. of rain per week during dry periods. Insect damage, normally considerable in Trinidad, was markedly reduced by regular application of insecticides. Harvesting began about three months after sowing the

seed and continued during the dry season for a further two to three [illegible] (January to March). The variety used had been selected locally.

The seed was sown in October in boxes under a greenhouse, and the young seedlings were pricked out on to raised open seedbeds 3 to 4 ft wide, at a square spacing of 2 to 3 in. A uniform fertilizer treatment was applied to the nursery beds. Transplanting of seedlings to the field took place when they were 6 to 8 in. high.

RESULTS

Table 1. Mean responses to fertilizers in 10^3lb/acre

Year	*Levels of fertilizers cwt/acre*	*Planting distance, in.*	*Nitrogen as sulphate of ammonia*	*Phosphorus as triple super-phosphate*	*Potassium as muriate of potash*	*S.E.*
1957	1, 2	18	+8·4	+11·3	−6·6	±4·38
		30*	−0·8	− 0·7	+5·5	±2·53
		Mean response	+1·5	+ 2·3	+ 2·5	±2·19
		Difference	+9·2	+12·0	−12·1	±5·84
1958	0, 2	18	+6·6	− 0·3	+ 7·7	±2·10
		30*	+2·7	− 0·4	+ 1·2	±1·21
		Mean response	+3·7	− 0·3	+ 2·8	±1·05
		Difference	+3·9	+ 0·1	+ 6·5	±2·80

* Average of responses at 24, 30 and 36 in.

The effect of spacing on the yields in the three experiments is shown in *Figure 1.* There appears to be a marked response in yield when the spacing

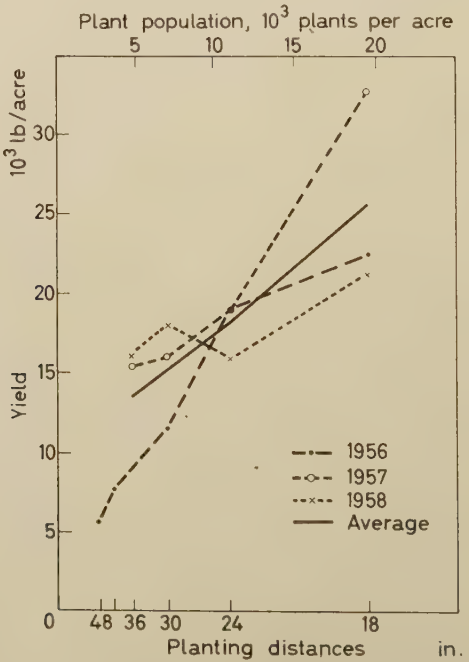

Figure 1. The relationship between plant population and yield of egg plant

ced. The average response is approximately linear over the range of spacings investigated so that the yield does not appear to be limited by even the closest spacings used. As all the plots were symmetrically sited on the cambered beds, it is possible that the smaller plots (closer spacings), confined to more fertile centre portions, may have been favoured to some extent. However, the results in 1958, when plots of approximately equal area were used, were similar, there being a significant rise in yield as the distance between plants was reduced to 18 in.

The mean responses to fertilizers are given (*Table 1*). There appears to have been some response to nitrogen, which was more marked at the closest spacing. The mean response was greater in 1958 probably because the lower level of application was zero in that year. With phosphorus and potassium, however, the responses were irregular and somewhat contradictory as shown, for example, by the differences in the responses at the closest and at the wider spacings in the two years. In 1957, plots at the closest spacing, but without fertilizer, were also included in the blocks. The fruit produced in these plots was of much lower quality than on the plots receiving fertilizer. Thus, although the results were not conclusive, there appears to be a need for fertilizer application especially if close spacing is adopted.

Table 2. Effect of spacing on quality of fruit. Proportion of fruit harvested in each grade at each spacing (per cent)

Spacing in.	*Year*	*0–7·5 oz.*	*7·6–11·5 oz.*	*11·6–15·5 oz.*	*15·6–19·5 oz.*	*Over 19·5 oz.*
18 × 18	1957	20	41	31	7	1
	1958	16	35	26	17	6
24 × 24	1957	17	39	32	10	2
	1958	21	31	25	17	6
30 × 30	1957	17	37	33	11	2
	1958	21	31	25	16	7
36 × 36	1957	14	30	35	17	4
	1958	20	34	24	16	6

In the last two experiments the effect of the treatments on the quality of the crops was examined. The fruits were graded by weight using five categories, with divisions at 7·5, 11·5, 15·5 and 19·5 oz. Only the smallest and largest fruits were unsuitable for marketing. The proportions of fruit in each grade were remarkably similar for all spacings, over 75 per cent of the fruit being of medium size (*Table 2*). There was a slight increase in the proportion of larger fruit, however, at the wider spacings, but, contrary to expectation, close spacing did not result in the production of a large number of small fruit of low quality.

DISCUSSION

With this crop, the main advantage of close spacing is that a greater yield can be obtained from a given area of land, without appreciably reducing the size of the fruits. The need for weeding was reduced, but not eliminated. Moreover, it was noted that at the closer spacings the

fruits were produced earlier and that the harvesting period was shorter. A more concentrated harvesting period implies lower costs for this operation, while an early crop will usually command higher prices.

Table 3. Cash returns at different spacings ($[W.I.] per acre)

Item	Spacing, in.			
	36	30	24	18
*Value of the crop at 6 cents per lb**	810	912	1 080	1 530
Total costs	520	550	660	770
Profit	290	362	420	760

* Average over the three years 1956–1958.

The cash returns at the different spacings were calculated (*Table 3*). The profit clearly increases as the spacing is reduced and, on the basis of these results, there were no indications of the maximum profit being attained within the range of spacings investigated. However, it is considered that in commercial practice the gains from spacings as close as 18 in. would not be so pronounced, since the plants would be liable to damage during weeding and harvesting.

SUMMARY

A series of experiments on the egg plant (*Solanum melongena*) to compare square spacings, varying from 36 in. to 18 in., was carried out at the Imperial College of Tropical Agriculture, Trinidad, from 1956 to 1958. The advantage of closer spacing for increased yields and net cash return was clearly demonstrated. There was also little variation in quality of fruit over this range of spacings.

ACKNOWLEDGEMENTS

We wish to thank the three post-graduate students: R. E. Tremeer, T. R. Barnes and L. J. Marenah for their part in carrying out the experiments in successive years, under the supervision of the first author, in part fulfilment of the requirements for the D.T.A.(Trin.).

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Book Reviews

BEEKEEPING IN THE TROPICS

F. G. Smith. Longmans, Green: London, 1960. *xvii*+265 *pp.* (illus.) 45*s*

In the New World tropics, the West Indies and Australasia, where there are no indigenous honeybees, thriving beekeeping industries have been built up around the introduced European race of *Apis mellifera* L., the Italian strain of this race usually being preferred. Attempts to introduce the European honeybee into tropical Asia and Africa have not met with much success, and it appears that commercial beekeeping in these parts of the world will have to be developed with indigenous strains. *Apis mellifera indica*, the honeybee of the Indian sub-continent and southeast Asia, is easily managed in hives, but its production is so small that there seems little prospect of its being used in the development of commercial beekeeping on a large scale. In contrast, good strains of the African honeybee *A. mellifera adansoni* are said to be among the most prolific, productive and vigorous bees known. They are, however, extremely vicious and sting readily in ' defence ' of the colony. Because they have the habit of building their nests in places where they are least wanted (privies, Governors' residences and places of worship), their opportunities to ' defend ' are numerous and the destruction of unwanted nests used to be one of the recurring chores of Government entomologists. Nevertheless it does seem that in this race lies the greatest hope of a beekeeping industry in Africa south of the Sahara and possibly in tropical Asia, and so attempts have been made in recent years to learn how to manage it. In this research Dr Smith has played a prominent part and the results of this work in Tanganyika form the backbone of this textbook which he hopes ' will prove of some value to the intending bee farmer who is starting up on his own '. If, having bought the necessary equipment, the intending bee farmer has 45*s* to spare, it undoubtedly will, for, as Dr Smith points out in his preface ' among all the excellent beekeeping literature there is not one book which meets the needs of those wishing to develop beekeeping as an industry under the conditions peculiar to the tropics'.

The first part deals with basic principles which include the biology, behaviour, diseases and enemies of the honeybee. In this section there is reference to much recent research and also valuable chapters on bee botany and on the economics of beekeeping. Dr Smith goes on in Part Two to discuss all forms of apiary equipment, from primitive hives to the modern frame hives that are now the standard equipment of all efficient beekeepers. Part Three deals with hive management and bee breeding and although methods of handling simple hives are discussed it is natural that the greater part of this section should be devoted to the techniques of using the modified Dadant type of hive on the assumption that most beekeepers will eventually graduate to these. In the final part Dr Smith discusses the handling of the

crop (both honey and beeswax) once it is removed from the hives, and in the closing chapter he provides notes for those who though not active beekeepers themselves may be concerned in the development of a beekeeping industry.

As becomes a book written primarily for the practical man the style is simple and direct: ' A method of keeping newly hived bees in the hive which one hears recommended is to put a queen excluder under the brood box. Do not have anything to do with it '. Unfortunately this is not always maintained and the vacillation between the imperative and passive tenses is sometimes irritating. Lapses into colloquialisms such as ' the assistance of a boy or two ', which, if not resented in Africa, is liable to be misunderstood elsewhere, should not occur in a textbook. Fortunately these and anthropomorphisms—'they [the drones] seem to be too lazy to feed themselves and prefer to beg food from busy workers '—without which it seems almost impossible to write a book on bees, are not sufficiently common to be obtrusive.

The book is well illustrated with clear line drawings and excellent photographs in black and white and in colour, and useful appendixes provide technical information on the quality of honey and give a guide to further reading and to beekeepers' Associations in the tropics. To suggest that the price is a little high for an intending African beekeeper is not to imply that it is out of proportion to the value of the book; that is certainly not so.—M.H.B.

MANIOC IN AFRICA

W. O. Jones. Stanford University Press: California, 1959. *ix*+315 *pp.* (maps.) 54*s*

The appearance of a book-length treatment of cassava in Africa is very welcome, since this is one of several important food crops which have been relatively neglected in the literature. Obviously as the result of much painstaking reading, which is well indexed in the book, Dr Jones has collected a mass of useful facts and figures, though no particular new perspectives arise from his analysis of them.

In the tradition of studies from the Stanford Food Research Institute, the book gives much more weight to the distribution, uses and economics of the crop than to its agronomy. No complaint can be made about this; but since a section on cassava diseases is included, to write it without mentioning Storey's name or his work on mosaic resistance is rather Hamlet without the prince! In fact, the author appears gravely to underestimate the effect of mosaic in reducing cassava yields in Africa compared with other continents. There is also no mention of brown streak disease.

Some other aspects also appear not to be very fully covered. In the many pages devoted to distribution of the crop, there is no adequate discussion of the effects of altitude, prevalence of wild pig, and proximity of towns on its distribution and on the varieties grown. In the section on usage, cassava is not mentioned as the source of the ' Nubian gin ' or *waragi* of East Africa; nor is the medical evidence for an association between cassava eating and peptic ulcers discussed. The legal requirements in

certain territories for maintenance of a compulsory acreage of cassava which have widely affected the amount grown, have not been ferreted out.

Such mis-spellings as 'Achimoto' for 'Achimota' and 'Kwanda' (repeated) for 'Kawanda' cannot but irritate readers who know Africa.

For these reasons, the book cannot quite be held to reach the highest standards of some of the other Stanford Food Research Institute publications. The inclusion of a whole background chapter on 'Africa: Land, Climate and People' suggests that it is largely written for readers who do not know that continent. For them it will be a valuable work of reference; slightly less so for those who already have some knowledge of cassava in Africa.—G.B.M.

A NEW EARTH: AN EXPERIMENT IN COLONIALISM

ELSPETH HUXLEY. Chatto & Windus: London, 1960. 279 *pp.* (maps and illus.) 30*s*

The extensive achievements in Kenya of land consolidation, registration and enclosure are known by repute to most of those concerned with tropical agriculture. But these are only ultimately of importance in so far as they contribute to better farming; and the agricultural revolution which is actually taking place in Kenya with startling speed and heartening promise is all too little known outside the country's boundaries.

It is this gap that Mrs HUXLEY has set herself to fill with her customary competence. Her book is frankly journalistic in style, but in the very best style of that *genre*. It would be a thousand pities if, for that reason, it were not to be widely read by those professionally engaged in the field of tropical agriculture. Mrs HUXLEY is an author who can be relied upon to make quite sure of the accuracy of her facts, and not to distort the truth.

Such a readable book is particularly to be recommended to any who are embarking for the first time on life in Kenya, or indeed in any of the African countries. While it does not shrink from suggesting the frailties of human nature, both European and African, in the carrying out of agricultural policies which are obviously beneficial, the overall picture presented is one of which all communities in Kenya may justifiably be proud. Herself brought up in Kenya, Mrs HUXLEY has in preparing this book visited and elicited the confidences of many African farmers, and makes us see their difficulties and achievements largely through their own eyes.—G.B.M.

ENVIRONMENTAL PHYSIOLOGY OF DOMESTIC ANIMALS
With particular reference to Livestock Breeding Problems in the Tropics

D. H. HILL. Ibadan University Press: Ibadan, 1957. 19 *pp.* (illus.)

Dr HILL and the Ibadan University Press are to be congratulated on producing this record of a lecture given before the Philosophical Society of the University College of Ibadan.

The subject is relatively new and most important, and we must look to the new University Colleges serving tropical areas for future advances in this field. It is, perhaps, a disappointment to the reader to find that most

of Dr HILL's paper is a review of published work carried out elsewhere although in his opening remarks Dr HILL states that his interest and experience includes a ' few experiments and observations at the University College, Ibadan '. Full details of these ' experiments and observations ' would have been welcome.

The reviewer was surprised to find that Dr HILL did not refer to a similar publication produced by the University College of Rhodesia and Nyasaland, Salisbury, *The Survival of Animals in Hot Deserts* by Professor E. B. EDNEY. This work, published in the same field as Dr HILL's review, deals with the subject of climatic adaptation from the point of view of the zoologist.

A few minor alterations would add to the value of this publication. Although the list of references is given at the back of the booklet, the text does not give the author's name and date in such a manner that the exact work of reference can be ascertained easily. Thus the reference list includes six papers by D. H. K. LEE whilst the text does not differentiate between these six separate references.

There are two minor errors in the text. On page 4 FINDLAY is mis-spelt Finland, and on page 17 the ' Jamaica Hope Breed ' of cattle is incorrectly referred to by its old name, the ' Mount Hope Jerseys '. Again, on page 6 the sentence appears ' this " heat-centre " is said to be activated according to the temperature of the blood bathing its cells '. Experimental work has shown that anaesthetization of the skin will result in a delay in the dilation of the blood vessels supplying the skin, and thus in a reduced heat loss due to surface evaporation. It is, therefore, obvious that the ' heat-centre ' of the brain is principally activated by reflexes from the skin, whereas the author apparently regards this later mechanism as secondary to the stimulation of the hypothalamus by increased blood temperature.

However, the above errors and deficiencies in the work are minor in nature and the essay is a valuable contribution towards clearer thinking in this important subject. It is essential reading for all those teaching subjects related to zoology and animal husbandry in tropical regions.

The reviewer would like to conclude by recommending other University Colleges to follow this admirable practice of printing essays of this nature in a form which is readily available for all to read.—P.N.W.

A REVIEW OF THE BIOLOGICAL CONTROL OF INSECTS AND WEEDS IN AUSTRALIA AND AUSTRALIAN NEW GUINEA

F. WILSON. *Technical Communication No. 1.* Commonwealth Institute of Biological Control. Commonwealth Agricultural Bureaux. Farnham Royal, Bucks., 1960. 102 *pp.* 25*s*

The colonization of Australia has taken place during a period in which global transport has become progressively easier. It is perhaps not surprising therefore that many of the country's principal pests and noxious weeds should be introduced species and in consequence, suitable subjects for biological control. This, however, is not the only reason why Australia should be such an interesting testing ground for biological control. It is an island continent made up of a number of diverse areas separated from each other by mountain barriers or great stretches of desert. Though not a

pre-requisite for successful biological control, the existence of such ecological islands does offer the method a greater chance of success, especially when to the ' insularity ' can be added a fair measure of equability of climate. In many instances, economics, governed by low population densities and the large areas over which the pest exists, have determined that control by natural enemies is the only method that can be considered. Oddly enough, interest in biological control in Australia was initially aroused, not by the introduction of a pest from elsewhere, but by the reverse process. It was from Australia that the cottony-cushion scale (*Icerya purchasi*) was imported into the Californian citrus groves and it was in Australia that search was made for the natural enemies of this pest that at one time threatened the Californian citrus industry with extinction. The success of the Australian Coccinellid beetle (*Rodolia cardinalis*) in controlling *Icerya purchasi* gave rise to the hope in Australia that biological control would similarly solve some of the country's principal insect problems. Interest in the possibility of the biological control of weeds quickly followed, and the successful control of prickly pear (*Opuntia* spp.) by the caterpillar of a small Argentinian moth (*Cactoblastis cactorum*) has become a well-known textbook example.

Over a period of some sixty years, attempts have been made in Australia and in Australian New Guinea to control, through the introduction of natural enemies, no less than fifty five insect pests (both native and exotic) and ten species of weeds. The time has now come to attempt to assess this work and this Mr Wilson has done objectively in a comprehensive and detailed review. As he rightly points out, biological control is successful to the extent that it reduces the loss and trouble caused by insect pests or weeds and it is unfair and unrealistic to apply to the method the extreme concepts of ' successful ' when the results are spectacular and ' unsuccessful ' when they are not. Results that may at first appear somewhat modest appear in better perspective when the often considered difficulties involved in the introduction, culture and liberation of natural enemies are borne in mind, and when the costs are compared with those of chemical control. These difficulties are discussed by Mr Wilson as are the adverse effects of insecticides on biological control in Australia.

This review is a valuable addition to the existing literature on biological control which is the first of a series of similar technical communications that the Commonwealth Institute of Biological Control hopes to publish. —M.H.B.

Recent Publications

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No. 6 British Guiana. The Rupununi Savannas (continued). The Intermediate Savannas. General Remarks. 1959, 15*s*

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No. 9 Grenada. 1959, 18*s*

No. 10 Jamaica. Parish of St Mary 1960, 14*s*

These and earlier publications can be obtained from the Library and Publications Department, Faculty of Agriculture, University College of the West Indies, St Augustine, Trinidad

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The following books written by members of the staff have recently been published:

Insect Life in the Tropics, by T. W. KIRKPATRICK. Longmans, Green: London. 35*s*

Bananas, by N. W. SIMMONDS. Longmans, Green: London. 45*s*

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